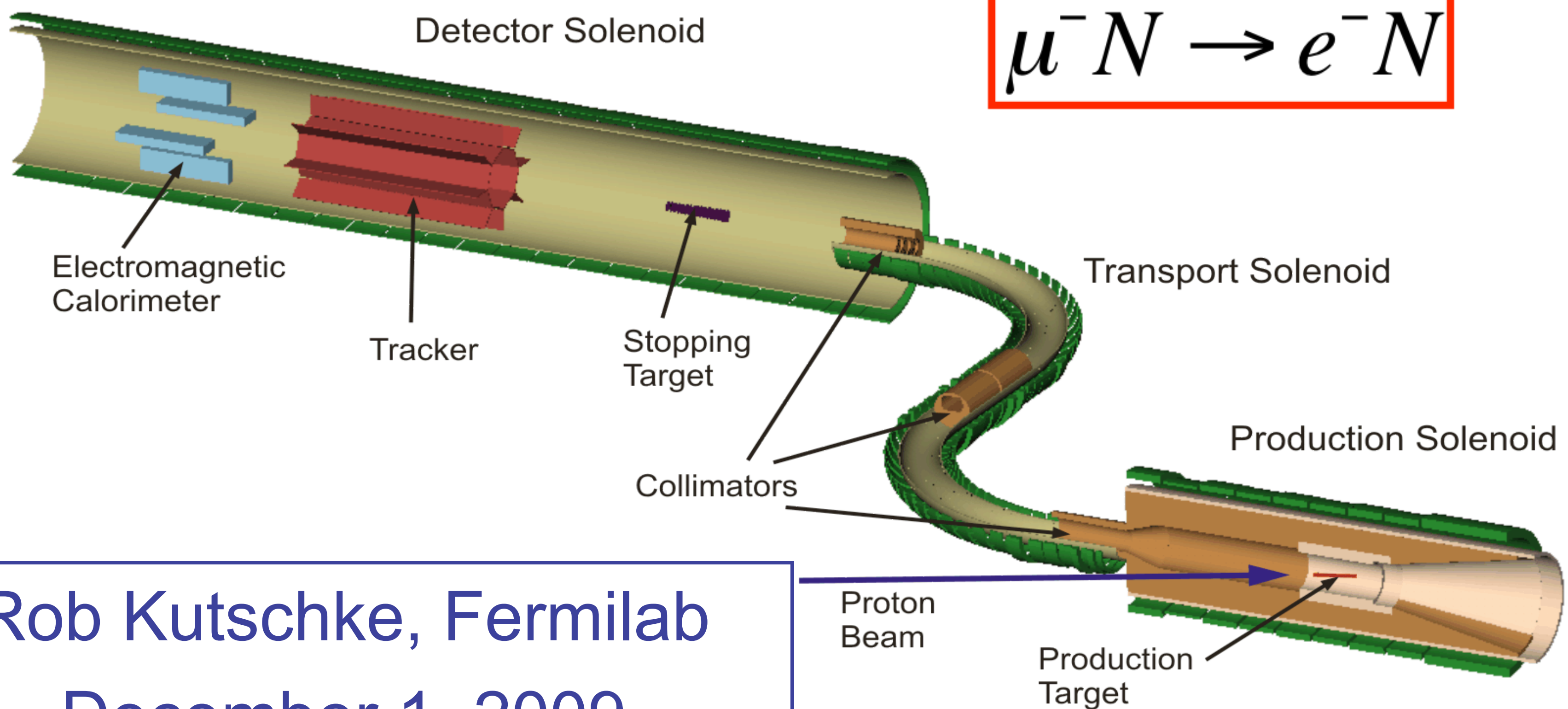
Mu2e-doc-714-v2

The Mu2e Experiment at Fermilab

$$\mu^- N \rightarrow e^- N$$



Rob Kutschke, Fermilab

December 1, 2009

(HEP Seminar at Notre Dame)

http://mu2e.fnal.gov

We have CD-0!

- Strongly endorsed by P5 in May 2008:
  - “The panel recommends pursuing the muon-to-electron conversion experiment …. under all budget scenarios considered by the panel.”
- Stage I Approval from Fermilab Directorate
  - November 2008.
- Critical Decision 0 (CD-0)
  - “Approval of Mission Need”
  - Received November 24, 2009.
  - This means DOE has said they want to do Mu2e.

The Mu2e Collaboration

96 Collaborators

Both HEP and Nuclear Physics groups.

Boston University
Brookhaven National Laboratory
University of California, Berkeley
University of California, Irvine
City University of New York
Fermilab
Idaho State University
University of Illinois, Urbana-Champaign

Institute for Nuclear Research, Moscow, Russia
JINR, Dubna, Russia
Los Alamos National Laboratory
Northwestern University
INFN Frascati
INFN Pisa,
Università di Pisa, Pisa, Italy
INFN Lecce, Università del Salento, Italy

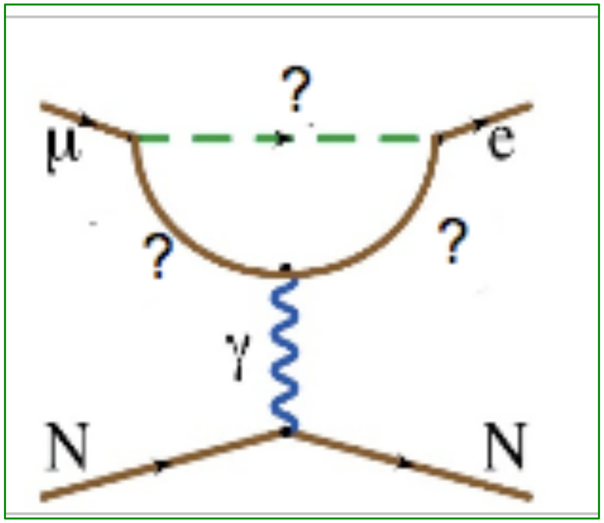
Rice University
Syracuse University
University of Virginia
College of William and Mary

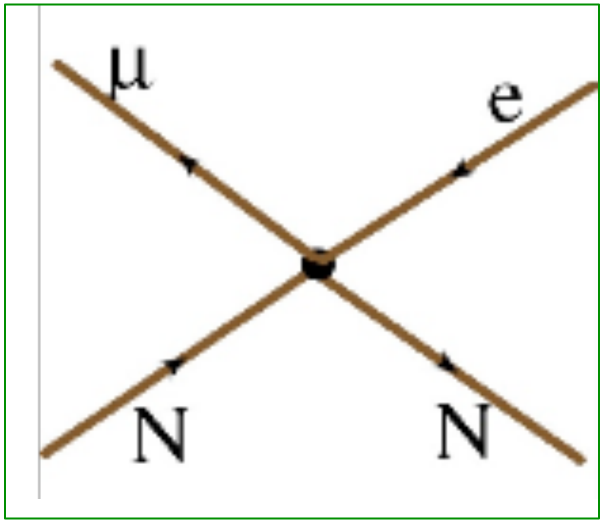
More opportunities for University groups.

Outline

- What is μ to e conversion? Why look for it?
- Cartoon of the experimental method.
- Theory overview.
- Details of the experiment.
- Backgrounds!
- Cost and Schedule.
- The Project X era.
- Conclusions.

$$\boxed{\mu^- N \rightarrow e^- N}$$





- Initial state: muonic atom.
- No neutrinos in the final state
- Coherent = intact nucleus; gamma coupling proportional to Z.
- Standard Model rate is non-zero! But is unmeasurably low.
- Many scenarios with new physics predict measurable rates.
- Sensitive to New Physics with masses up to O(10,000 TeV).

A Word of Caution

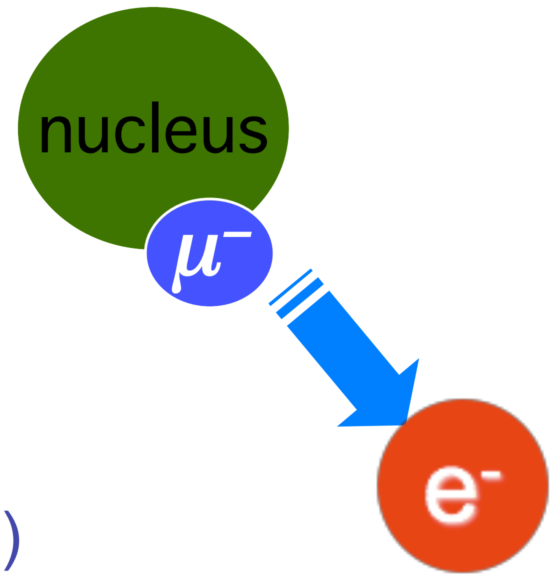
$$\cancel{\mu^{-} \rightarrow e^{-}\gamma}$$

- The MEG Collaboration is doing that experiment.
- See their web site:

  http://meg.web.psi.ch
- Or check SPIRES for publications by the MEGA Collaboration.

$\mu^- N \to e^- N$

- Single mono-energetic electron.
  - Energy $O(M_\mu)$.
  - Depends on Z of target.
- Recoiling nucleus (not observed).
  - Coherent: nucleus stays intact.
- Charged Lepton Flavor Violation (CLFV)
- Related decays:



$$\mu \to e\gamma \quad \mu \to e^+e^-e^+ \quad K_L^0 \to \mu e \quad B^0 \to \mu e$$

$$\tau \to \mu\gamma \quad \tau \to \mu^+\mu^-\mu^+ \quad D^+ \to \mu^+\mu^+\mu^-$$

Why Do Mu2e?

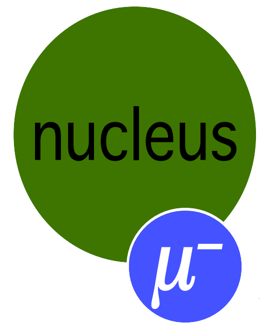
- Access physics beyond the Standard Model (SM).
  - Precision measurements and searches for ultra-rare processes complement direct searches at the highest available energies.
- Negligible standard model backgrounds.
  - Wide discovery window.
  - Any non-zero observation is evidence for physics beyond SM.
- Violates conservation of lepton family number.
  - Already observed in neutrino sector.
  - Addresses the puzzle of generations.
  - Strength (or absence) of particular CLFV signals can help remove ambiguities from new physics signals seen elsewhere.
- Overlap with the physics explored by measuring muon g-2.

Outline

- What is μ to e conversion? Why look for it?
- Cartoon of the experimental method.
- Theory overview.
- Details of the experiment.
- Backgrounds!
- Cost and Schedule.
- The Project X era.
- Conclusions.

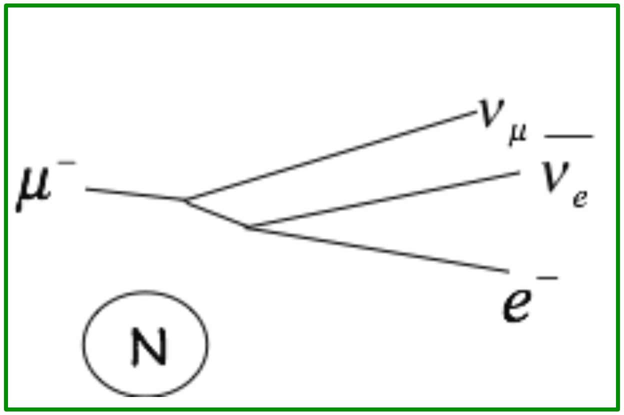
Mu2e in A Few Pages

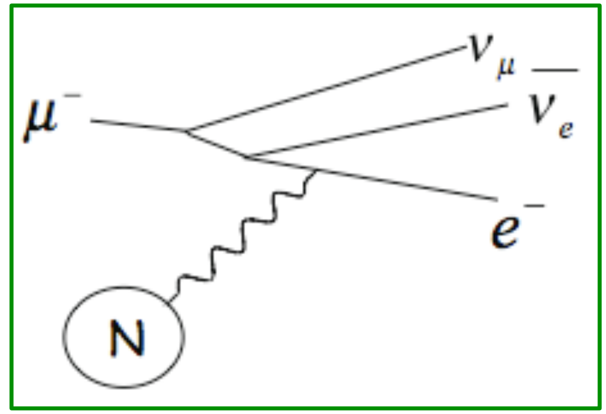
- Make muonic Al.
- Watch it decay:
  - Muon decay
    - Continuous E_e spectrum.
  - Muon capture on nucleus: 60%
    - Nuclear breakup: 2n, 2γ, 0.1 p
  - Signal:
    - Mono-energetic $E_e \approx$ 105 MeV
    - At endpoint of continuous spectrum.
- Measure E_e spectrum.
  - Is there a bump at the endpoint?



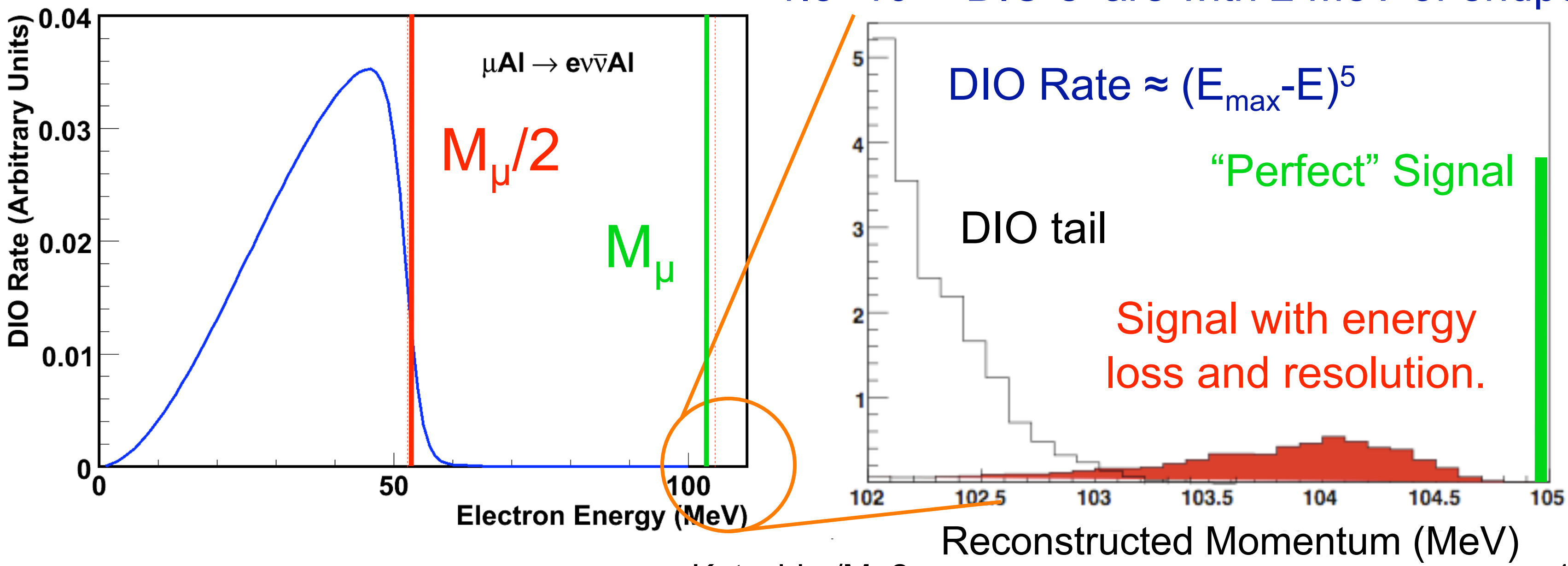
For Al:
Bohr radius ≈ 20 fm
Nuclear radius ≈ 4 fm
Lifetime: 864 ns

Decay-in-Orbit: Dominant Background





1.5×10^{-15} DIO e^- are with 2 MeV of endpoint.



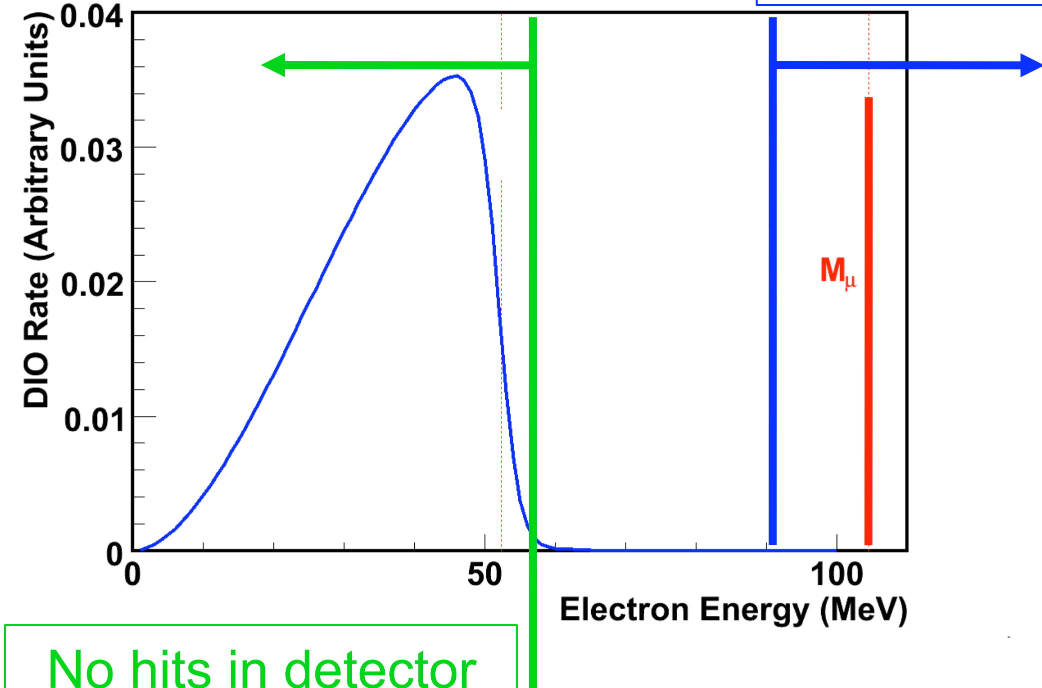
What do We Measure?

$$R_{\mu e} = \frac{\Gamma(\mu^- + (A,Z) \rightarrow e^- + (A,Z))}{\Gamma(\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1))}$$

- Numerator:
  - Do we see an excess at the E_e end point?
- Denominator:
  - Normal muon capture on Al.
- Sensitivity for a 2 year run (2×10^7 seconds).
  - $\approx 2.3 \times 10^{-17}$ single event sensitivity.
  - $< 6 \times 10^{-17}$ limit at 90% C.L.
- 10,000 × better than previous limit (SINDRUM II).

How do you measure 2.3×10^{-17} ?

Reconstructable tracks

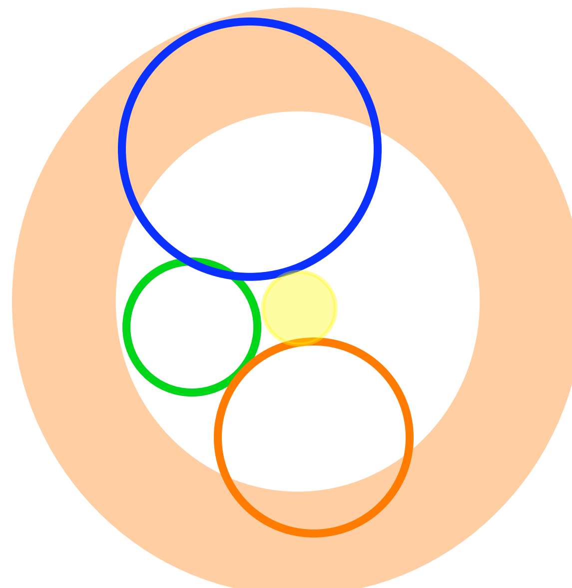


No hits in detector

Some hits in detector.
Tracks not reconstructable.

Instrumented Region

Target Foils



Beam's-eye view of a generic Tracker; magnetic field into the page.

$$p\cos\alpha = q \bullet B \bullet R$$

Outline

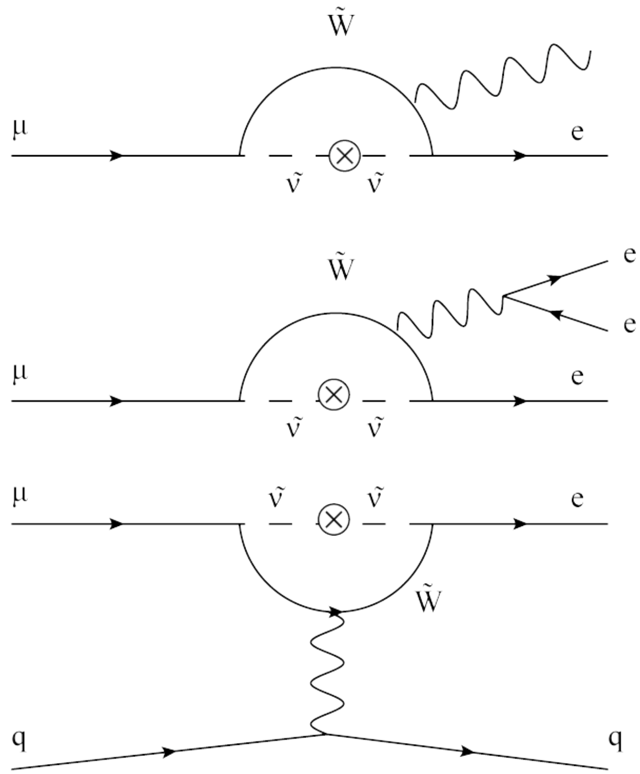
- What is μ to e conversion? Why look for it?
- Cartoon of the experimental method.
- Theory overview.
- Details of the experiment.
- Backgrounds!
- Cost and Schedule.
- The Project X era.
- Conclusions.

CLFV in Muon Decays

$$\mu^- \rightarrow e^- \gamma$$

$$\mu^- \rightarrow e^- e^+ e^-$$

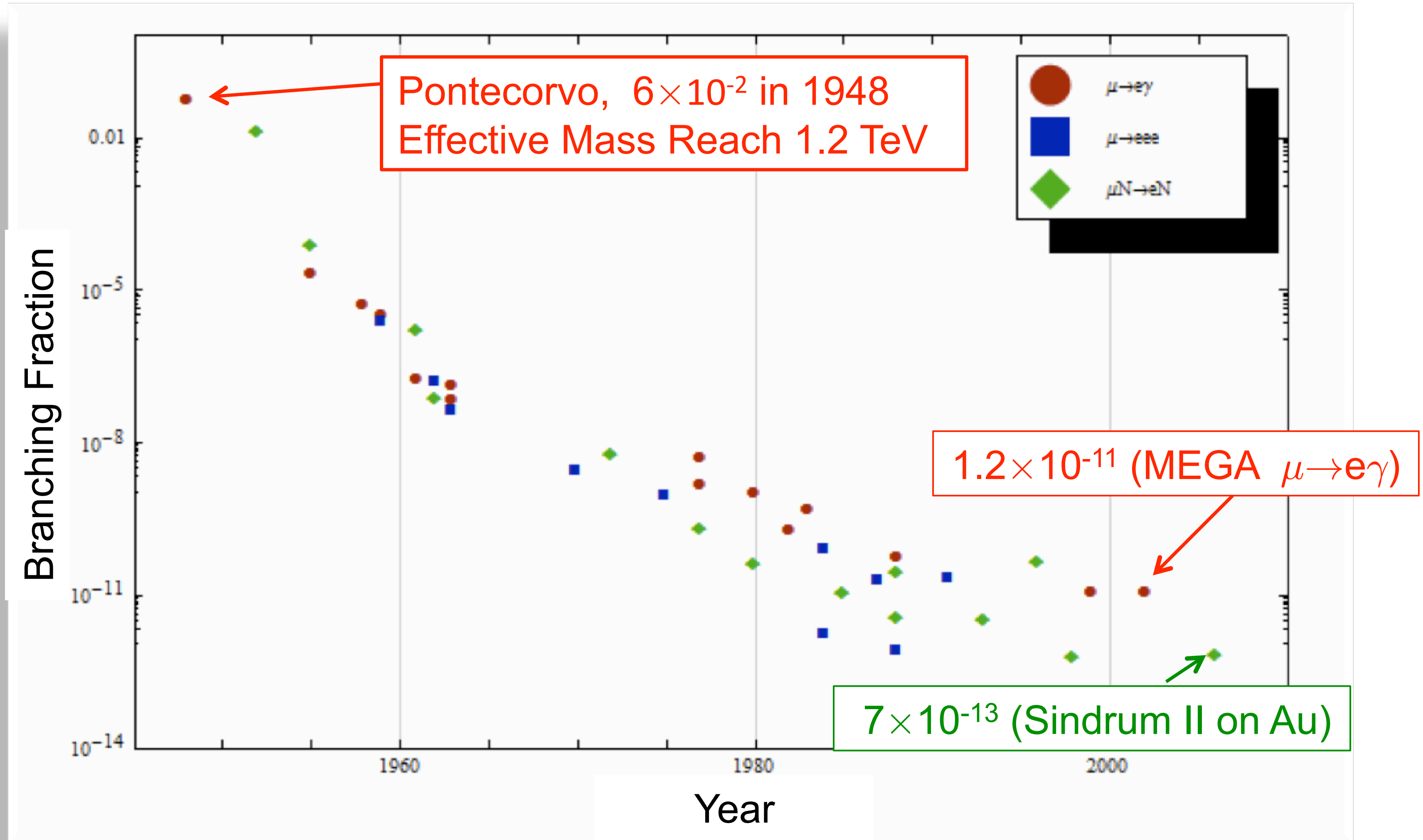
$$\mu^- N \rightarrow e^- N$$



- Loops shown with SUSY; also works with heavy ν.
- If loops dominate over contact terms, then rates follow ≈ 400: 2: 1
- Contact terms do not produce μ➔eγ; so conversion can dominate over μ➔eγ .

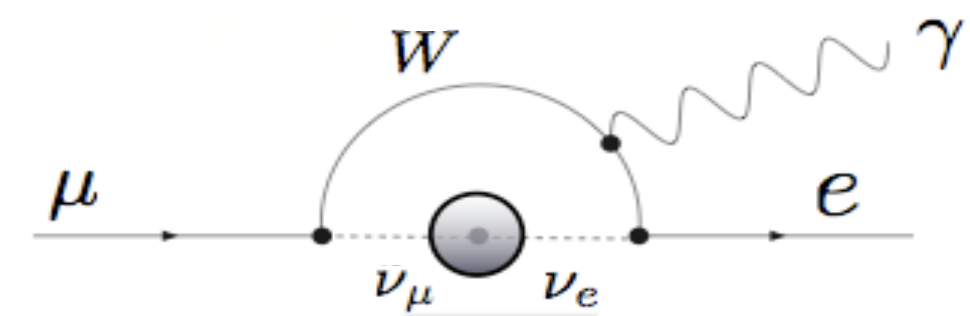
CLFV: Charged Lepton Flavor Violation.

History of μ LFV Measurements



Rates in the Standard Model

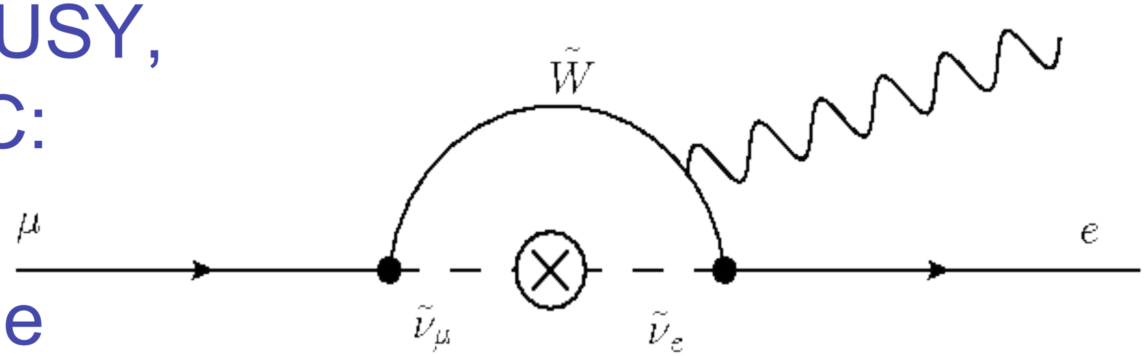
- With massive neutrinos, non-zero rate in SM.
- Too small to observe.



$$\mathrm{BR}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

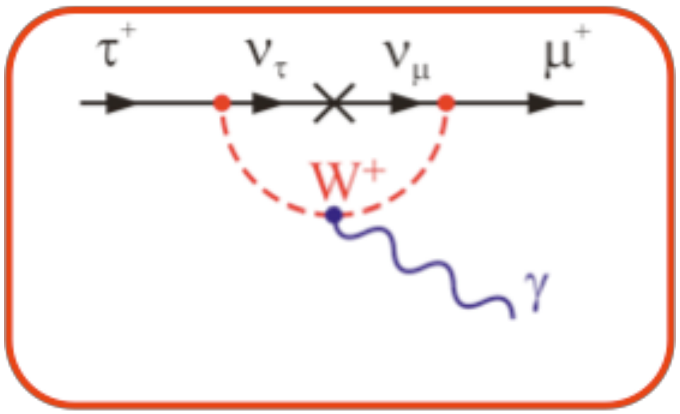
LFV and SUSY at the LHC

- For low energy SUSY, accessible at LHC: $R\mu e \approx O(10^{-15})$
- At Mu2e this same physics typically gives:
  - $\approx O(40)$ events on a background of ≈ 0.5 events.

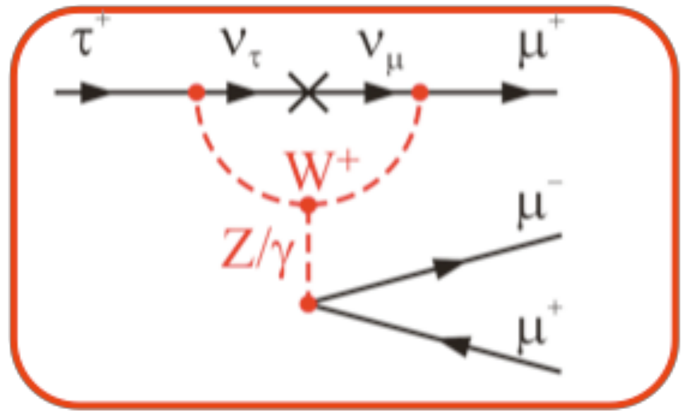


CLFV in Tau Decays

Lee, Shrock
Phys.Rev.D16:1444,1977



SM ~ 10^{-40}



SM ~ 10^{-14}

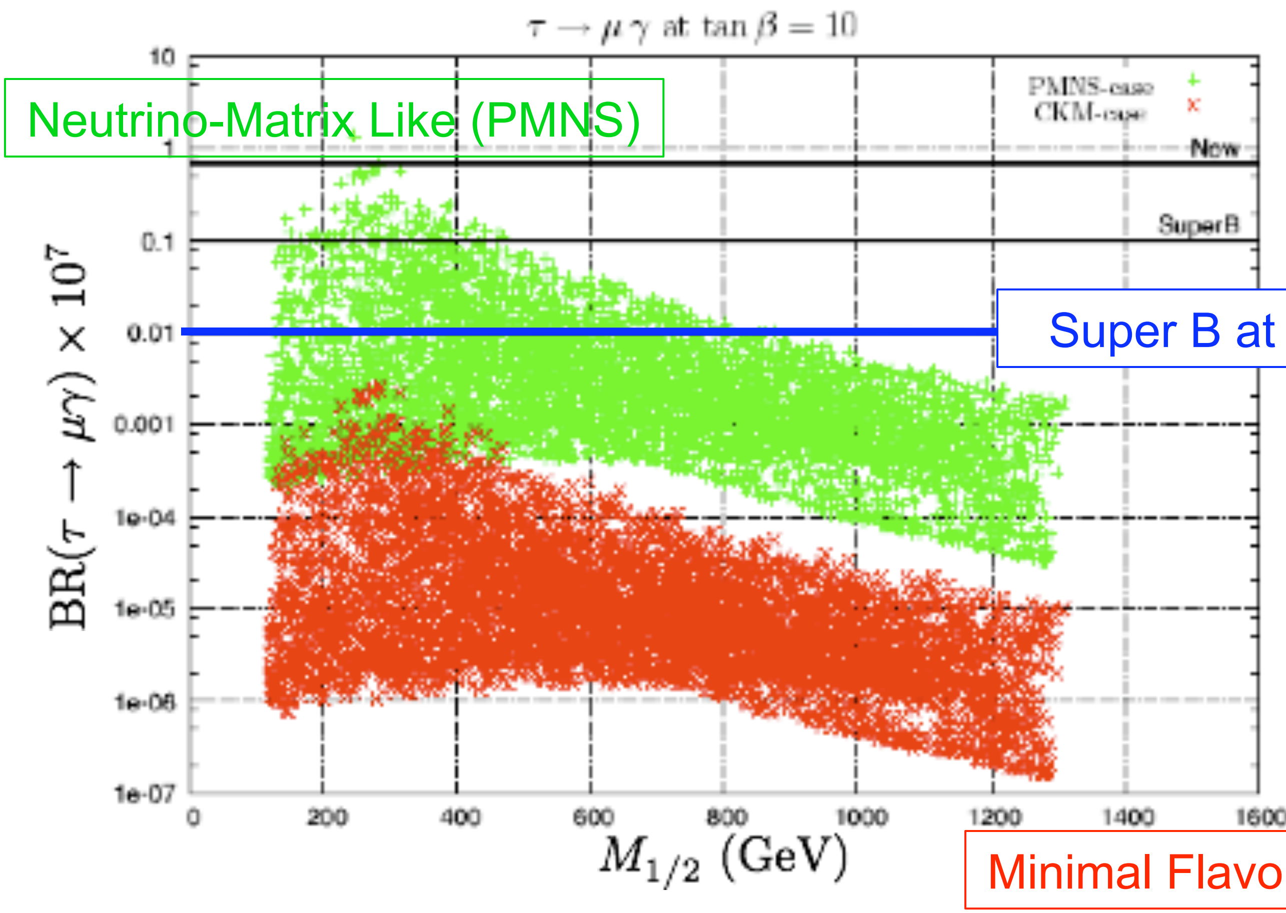
Pham, hep-ph/9810484

Beyond SM Rates higher than for muon decay; milder GIM suppression.

But only O(10^9 tau/year) at B factories, compared to 10^{11} muon/s at Mu2e/COMET.

- BaBar/Belle/CLEO working on CLFV in tau decay.
- Also in B and D decay.

Example of SUSY in Tau LFV

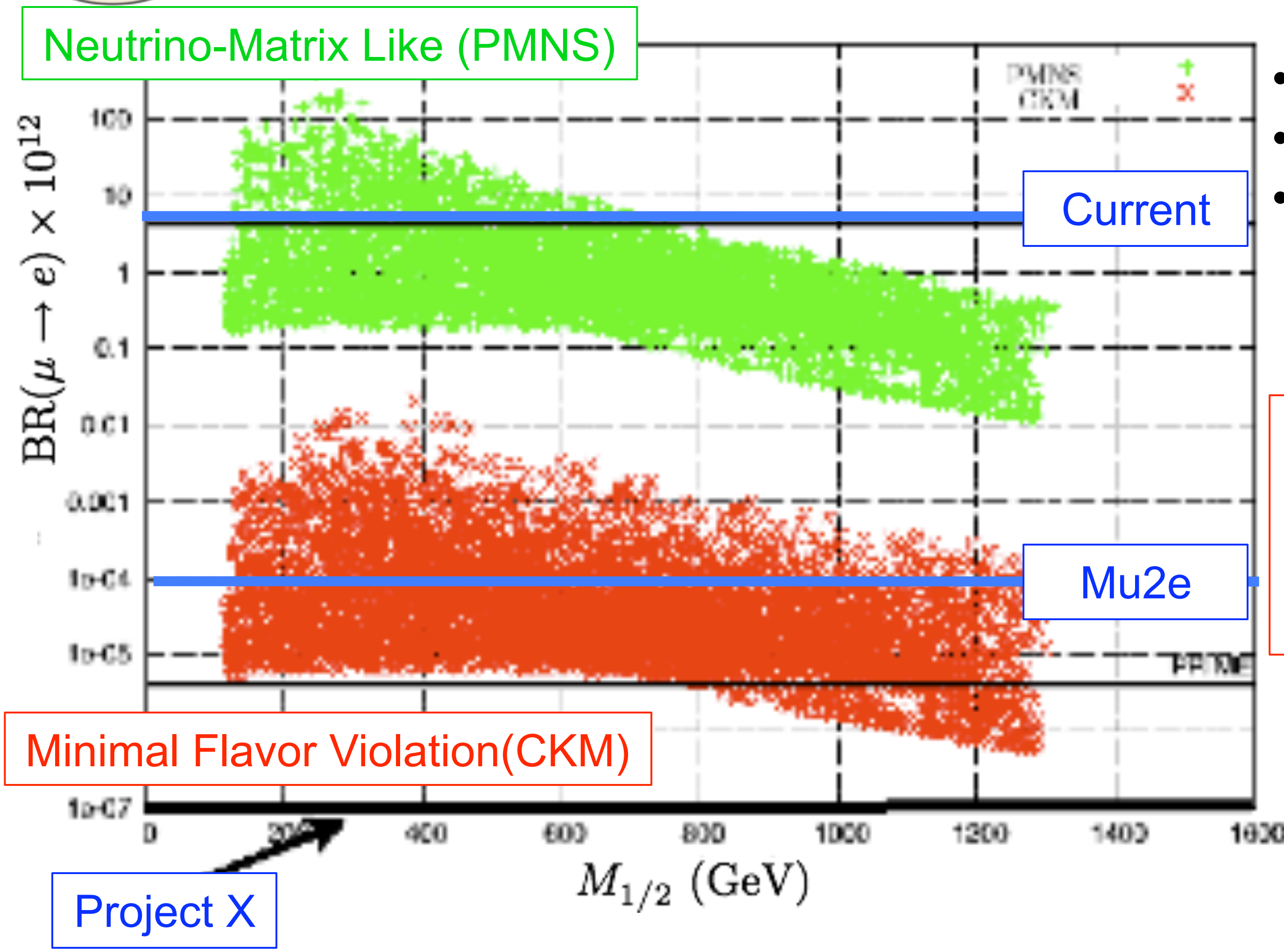


- tanβ=10
- SO(10)
- ν masses: see-saw.

A CLFV signal can help resolve ambiguities in LHC data.

L. Calibbi, A. Faccia, A. Masiero, S. Vempati hep-ph/0605139

Example of SUSY in Muon LFV



- tanβ=10
- SO(10)
- ν masses: see-saw.

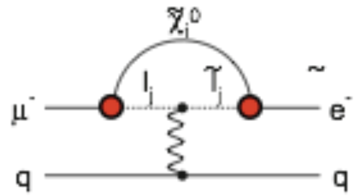
A CLFV signal can help resolve ambiguities in LHC data.

L. Calibbi, A. Faccia, A. Masiero, S. Vempati hep-ph/0605139

Contributions to μe Conversion

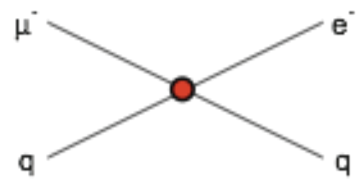
Supersymmetry

rate ~ 10^{-15}



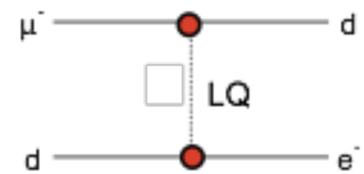
Compositeness

Λ_c ~ 3000 TeV



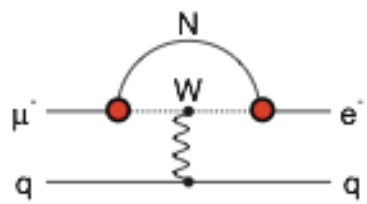
Leptoquark

$M_{LQ} =$
$3000\ (\lambda_{\mu d}\lambda_{ed})^{1/2}$ TeV/c^2



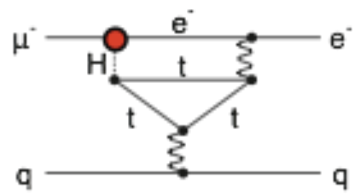
Heavy Neutrinos

$|U_{\mu N}U_{eN}|^2$ ~ 8×10^{-13}



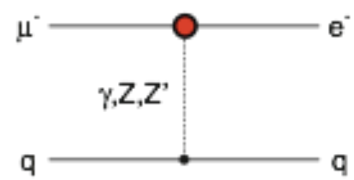
Second Higgs Doublet

$g(H_{\mu e})$ ~ $10^{-4} g(H_{\mu\mu})$



Heavy Z' Anomal. Z Coupling

$M_{Z'}$ = 3000 TeV/c^2



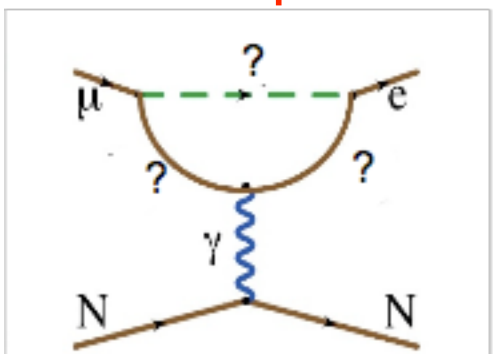
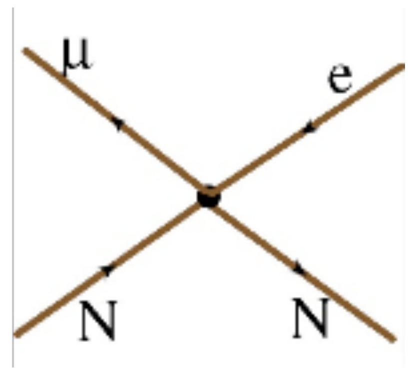
Sensitive to mass scales up to O(10,000 TeV)!

Do not contribute to μ→eγ

See Flavour physics of leptons and dipole moments, arXiv:0801.1826

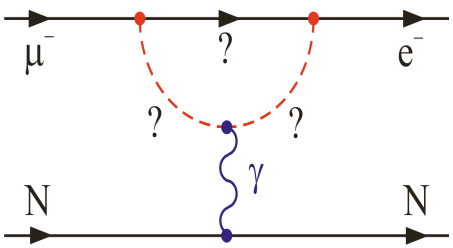
Parameterizing CLFV

$$L_{\mathrm{CLFV}} = \frac{m_\mu}{\boxed{(\kappa+1)}\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\boxed{\kappa}}{\boxed{(1+\kappa)}\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L)$$

Loops	Contact terms
	
Contributes to μ→eγ	Does not produce μ→eγ
SUSY and massive neutrinos	Exchange of a heavy particle
Dominates if κ<<1	Dominates if κ>>1

Sensitivity to High Mass Scales

Loops



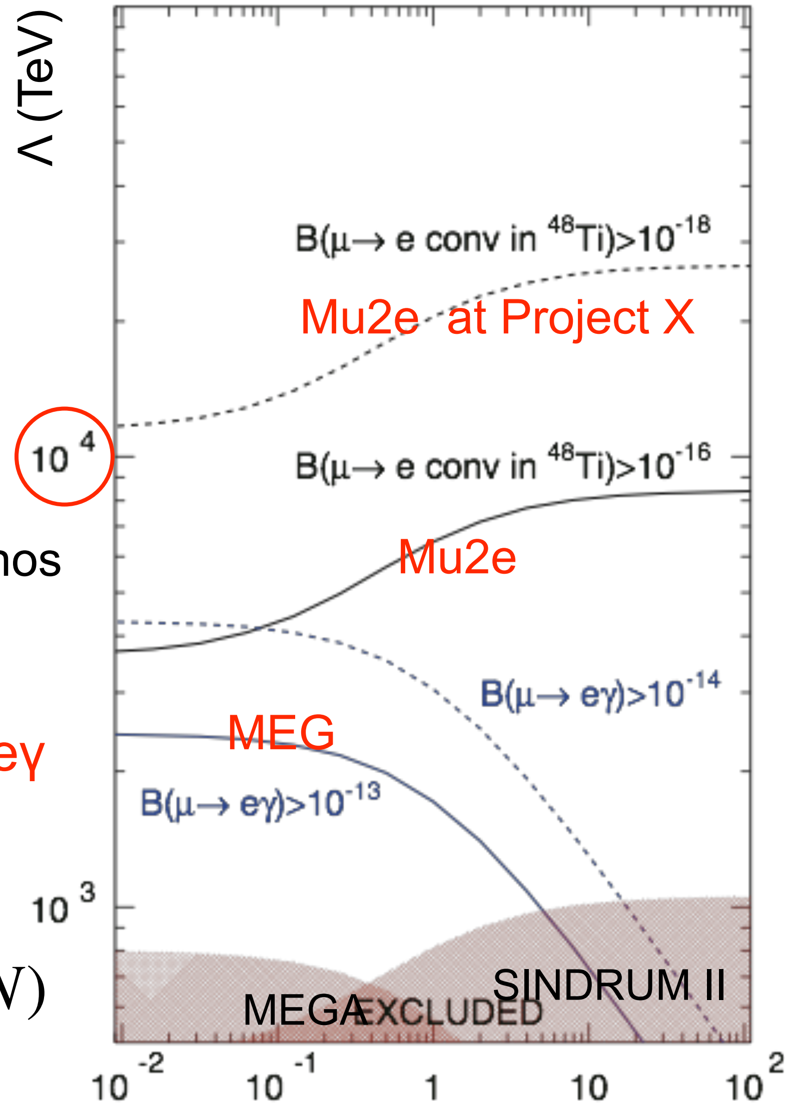
SUSY; massive neutrinos

Dominates if κ<<1

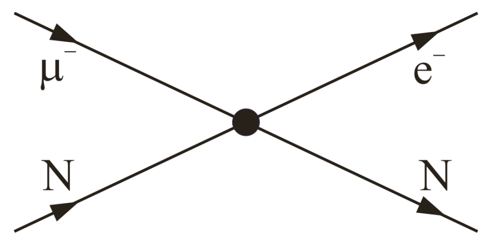
Contributes to μ→eγ

$$\Gamma(\mu \rightarrow e\gamma)$$

$$\approx 300\ \Gamma(\mu N \rightarrow eN)$$



Contact terms



Exchange of a new massive particle

Dominates if κ>>1

Does not produce μ→eγ

$$\Gamma(\mu N \rightarrow eN)$$

$$>> \Gamma(\mu \rightarrow e\gamma)$$

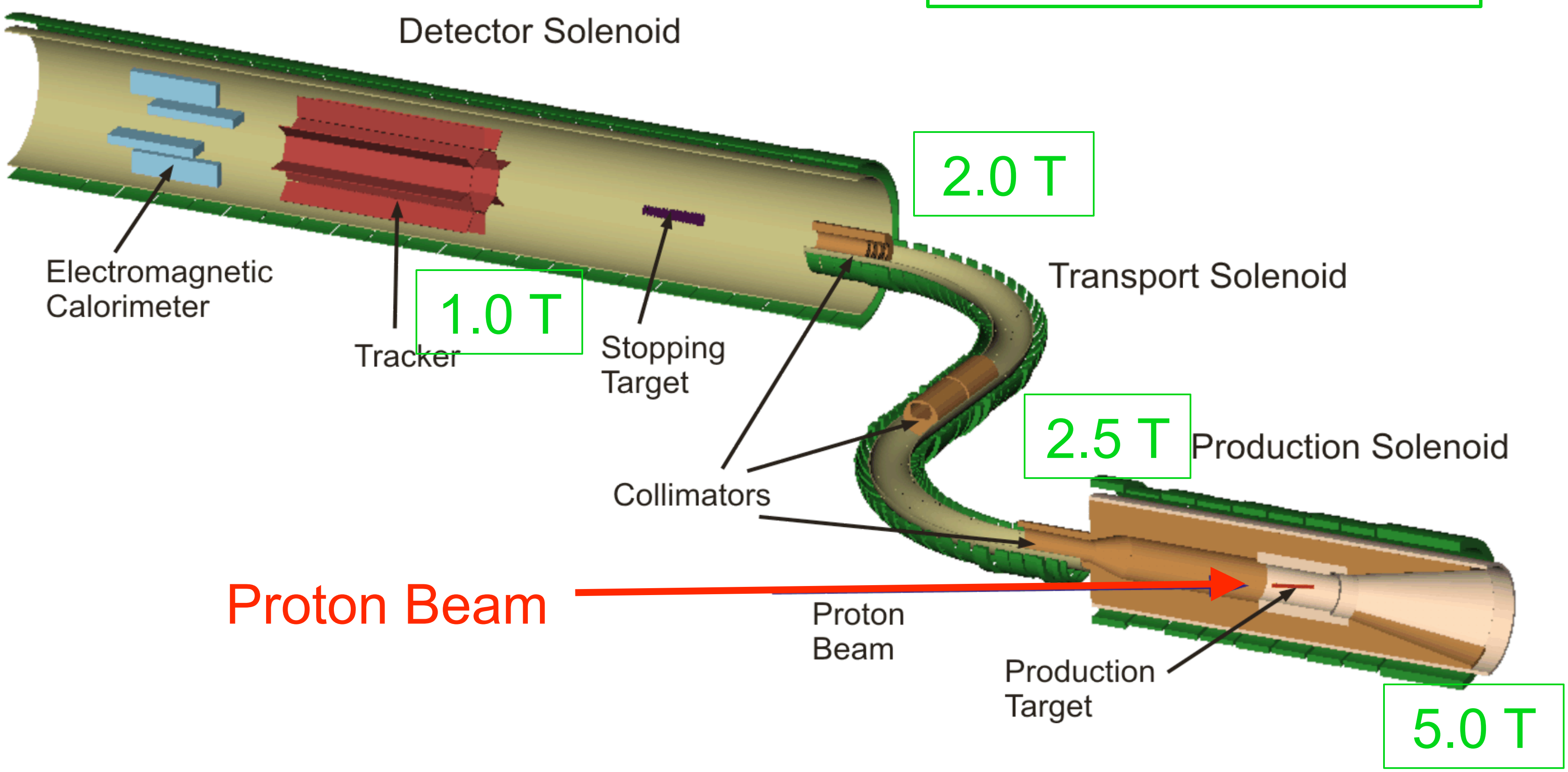
Outline

- What is μ to e conversion? Why look for it?
- Cartoon of the experimental method.
- Theory overview.
- Details of the experiment.
- Backgrounds!
- Cost and Schedule.
- The Project X era.
- Conclusions.

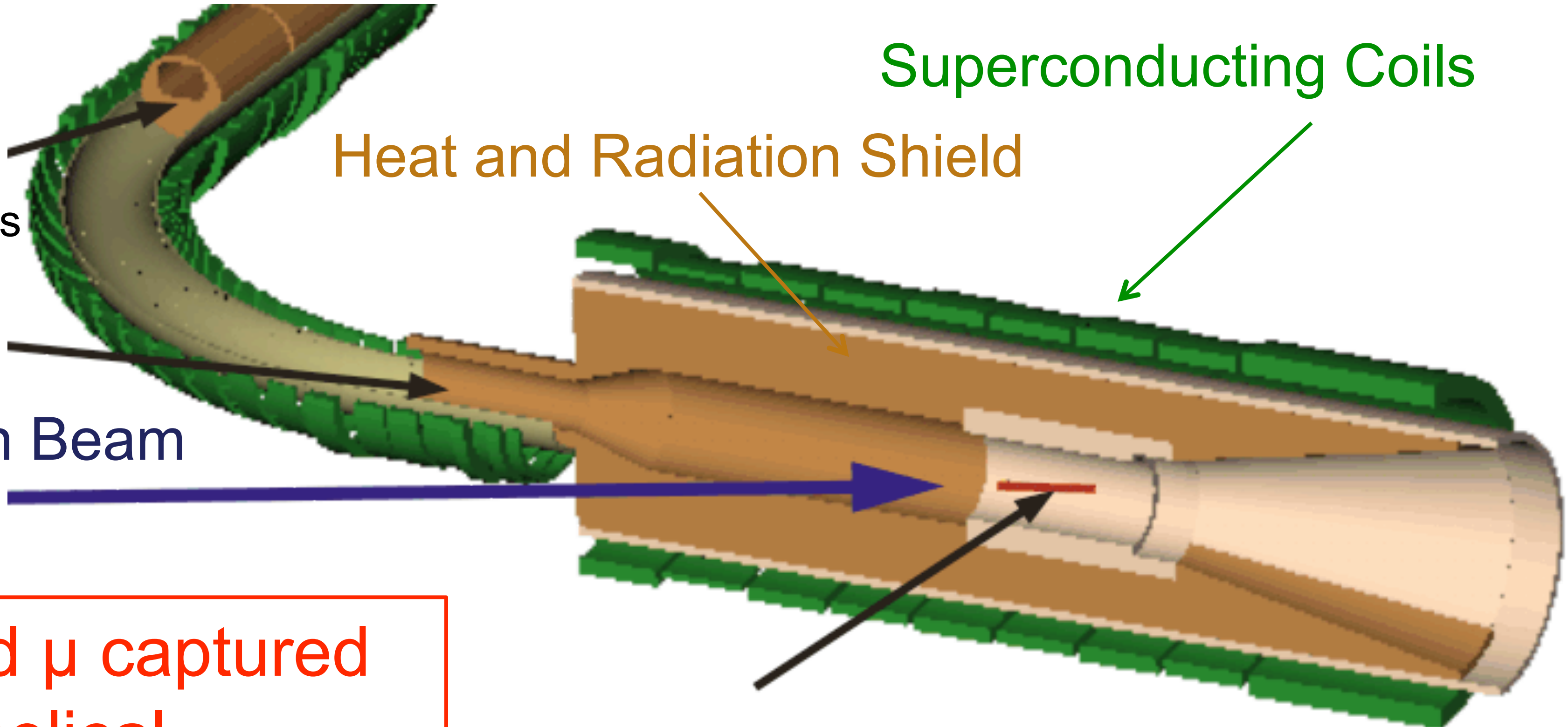
A Backscattered Muon Beam

Tracker + ECAL: Uniform 1.0 T

Graded Solenoids:
Magnetic Mirror



Production Solenoid

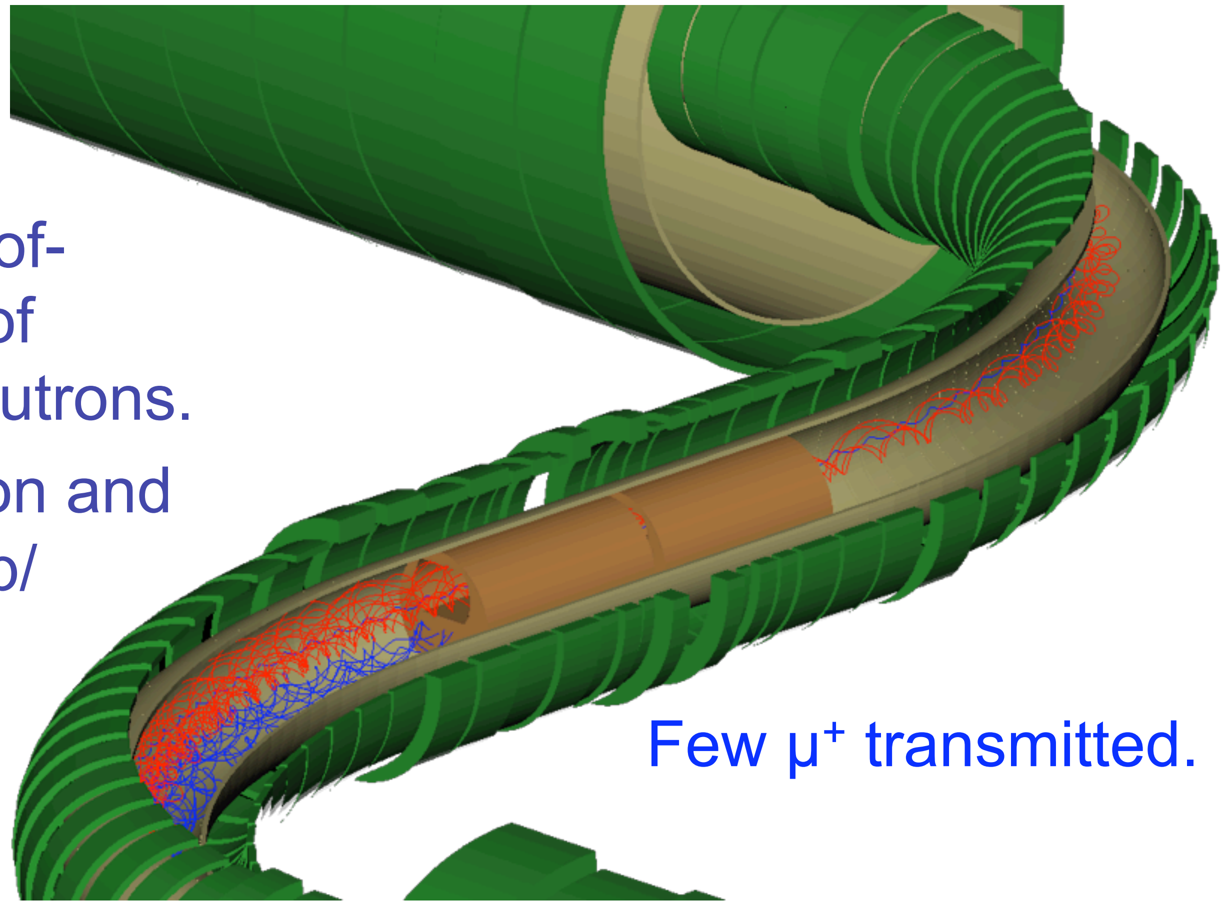


π and μ captured into helical trajectories

$$\boxed{p\ Au \rightarrow \pi^- X \rightarrow \mu^- X}$$

Transport Solenoid

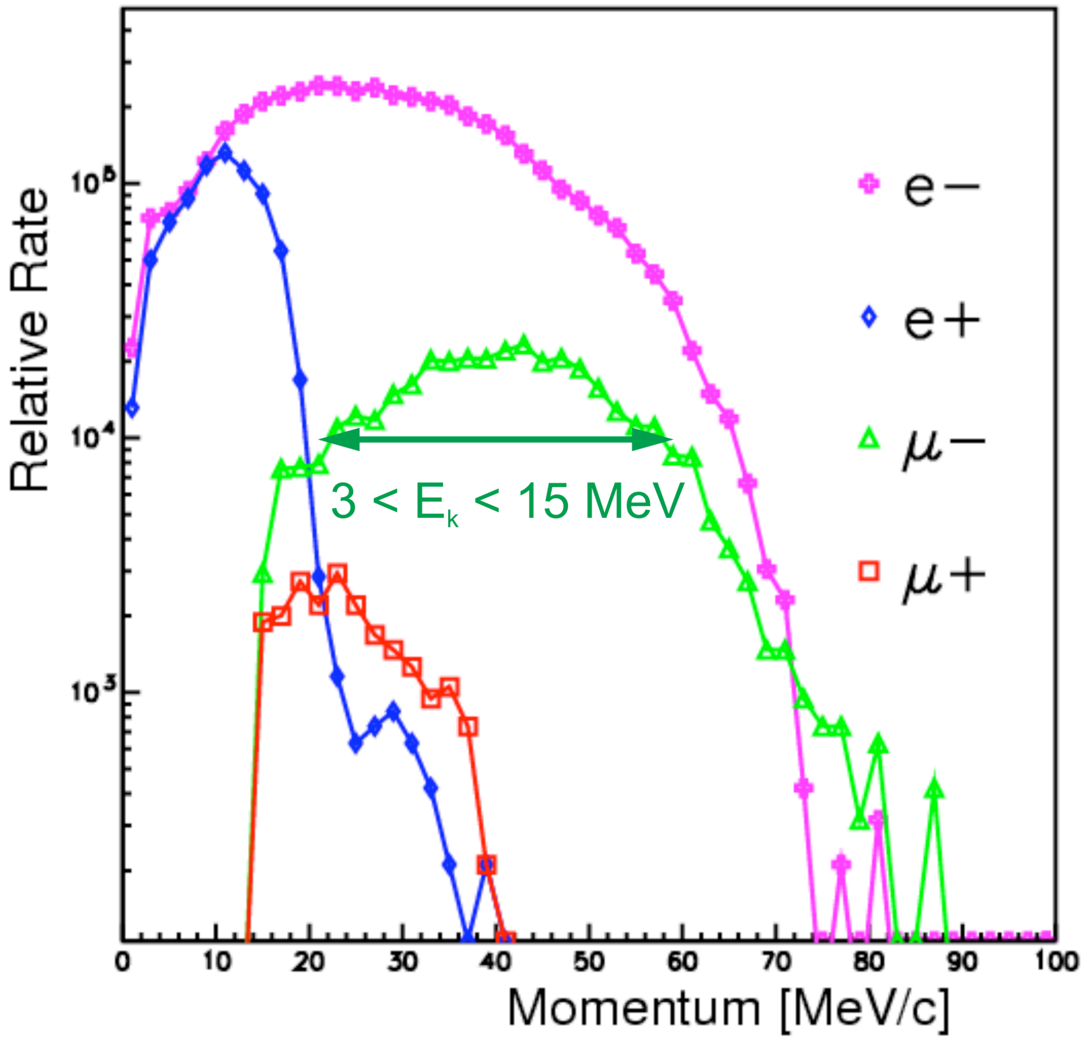
- Curved solenoid:
  - Eliminates line-of-sight transport of photons and neutrons.
  - Negative/position and particles shift up/down.
- Collimators sign and momentum select the beam.



Few μ^+ transmitted.

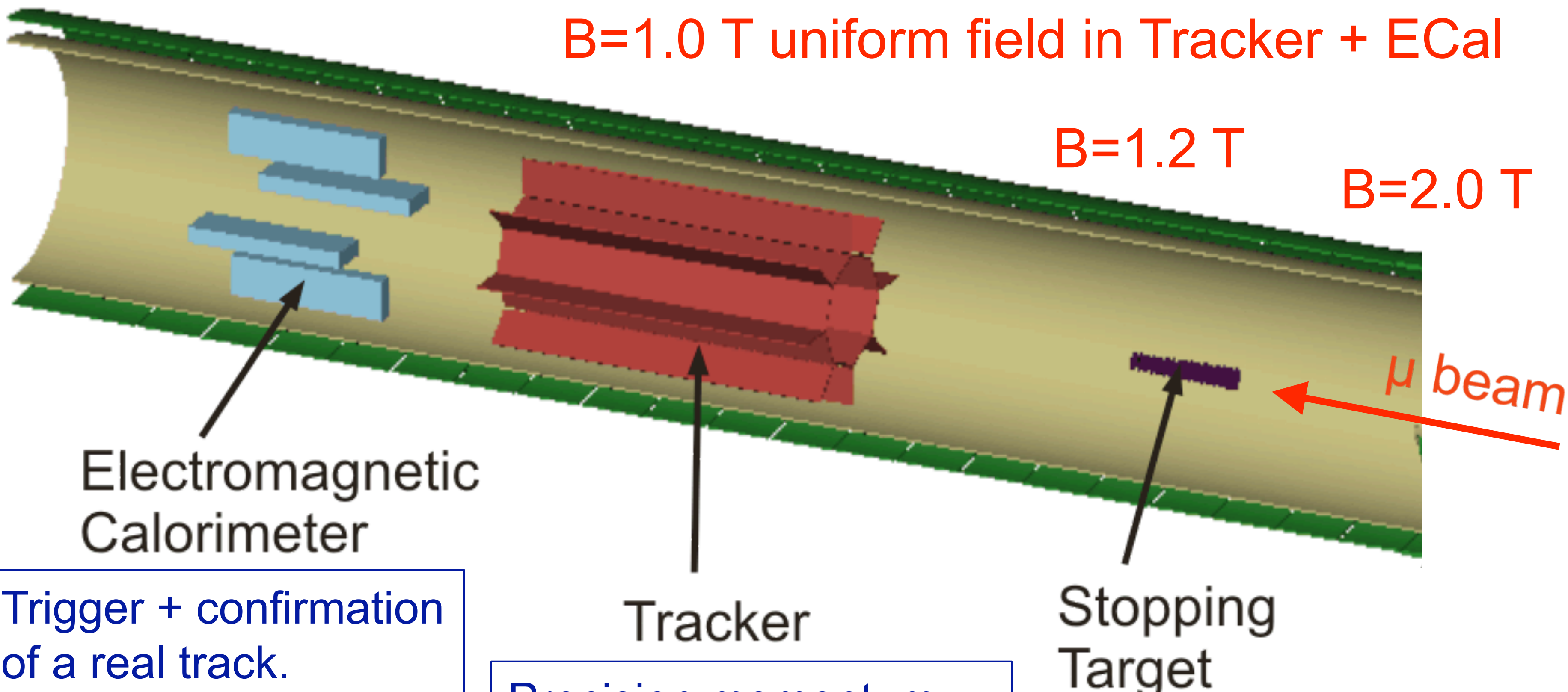
13.1 m along axis × *~0.25 m*

Particle Content of Muon Beam



- Plus pions, which are an important source of background.

Detector Solenoid and Detector



Trigger + confirmation of a real track.

Precision momentum measurement:

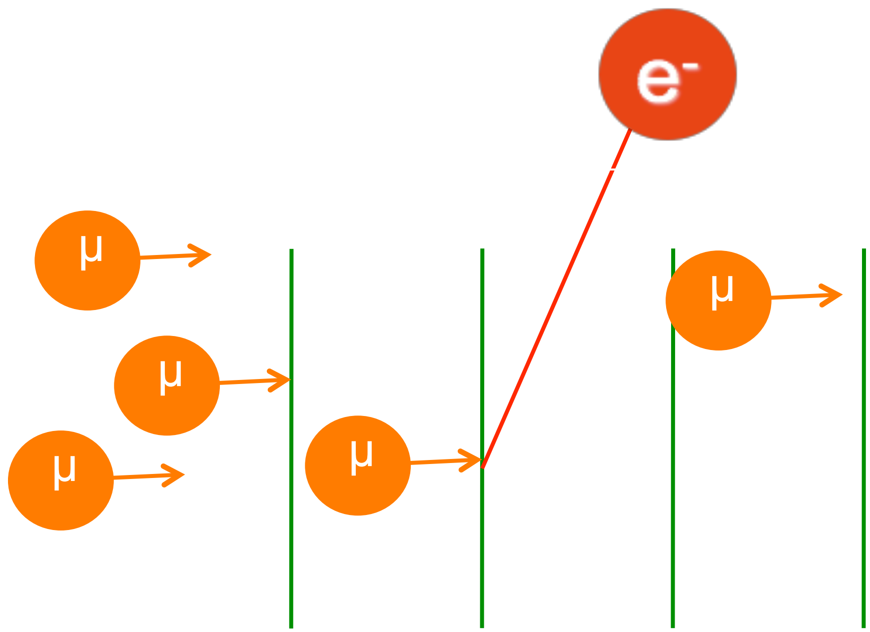
In graded field

Require:

$\sigma(p) \approx 150$ keV at p=105 MeV

At the Stopping Target

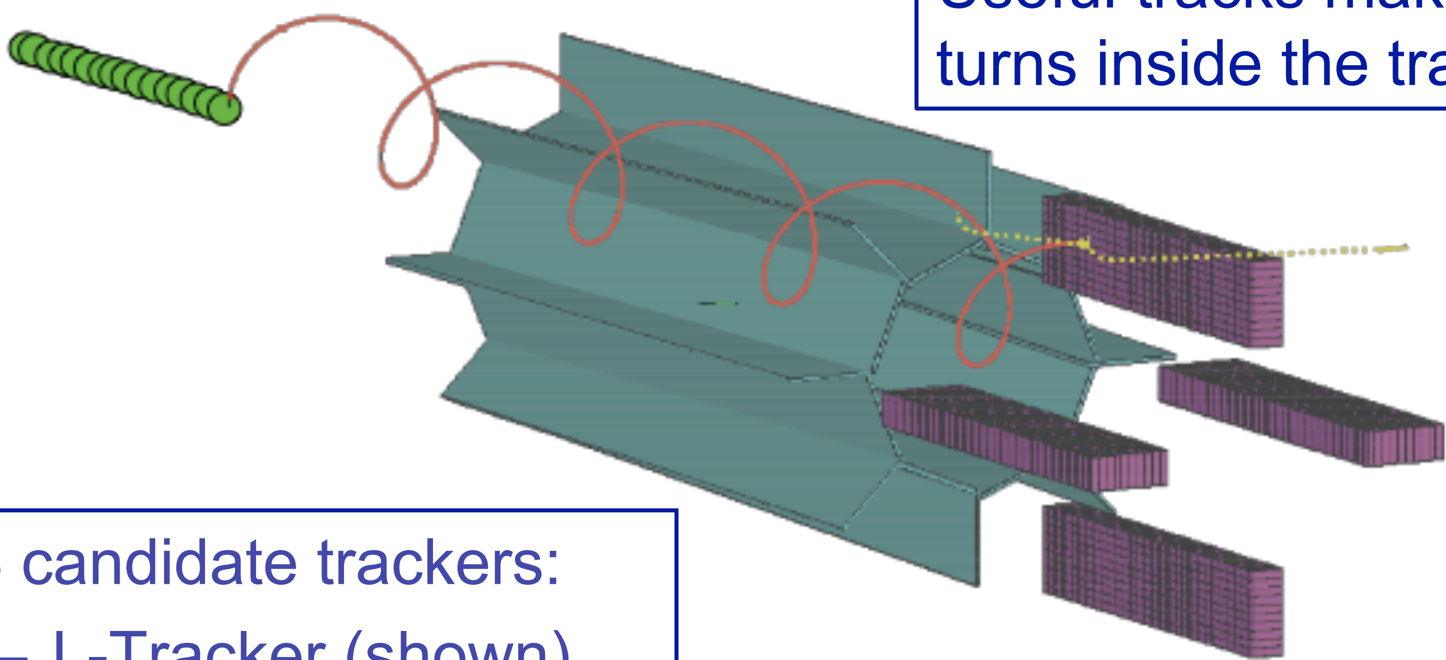
- Pulse of low energy μ^- on thin Al foils.
- 1 stopped μ^- per 400 protons on production target.
  - X-ray cascade emitted during capture: normalization!
- Electrons pop out of foils (lifetime of 864 ns)



- 17 target foils
- 200 microns thick
- 5 cm spacing
- Radius:
  - ≈10. cm at upstream
  - ≈6.5 cm at downstream

Detector

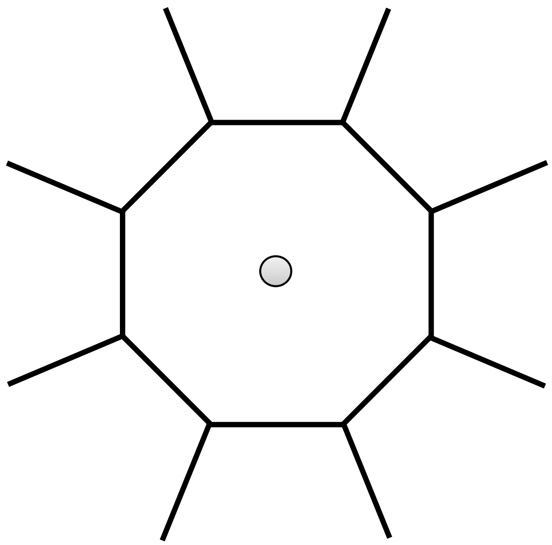
Useful tracks make 2 or 3 turns inside the tracker.

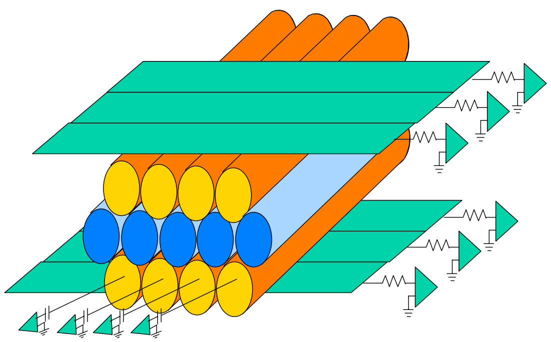


- 3 candidate trackers:
  - L-Tracker (shown)
  - T-Tracker
  - I-Tracker

L-Tracker (L=Longitudinal)

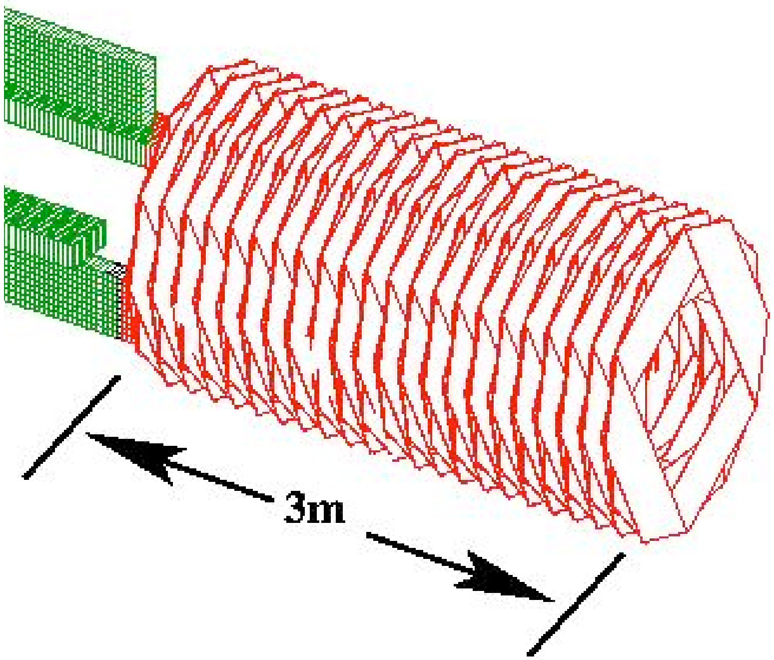
XY Cross-section of LTracker





- Octagon + vanes.
- ≈ 2800 axial straws in vacuum
  - ≈ 2.6 m long; 5 mm diameter
  - 25 μm wall thickness
- 3 layers; hex close packed.
  - Resistive walls on outer layers.
  - Cathode pads for z position.
- p_T < 55 MeV curls inside octagon.
- Issues:
  - Mechanical design; especially the cathode sheets.
  - High rates on resistive straws not yet demonstrated.
  - Enough measurements/track?

T-Tracker (T=Transverse)

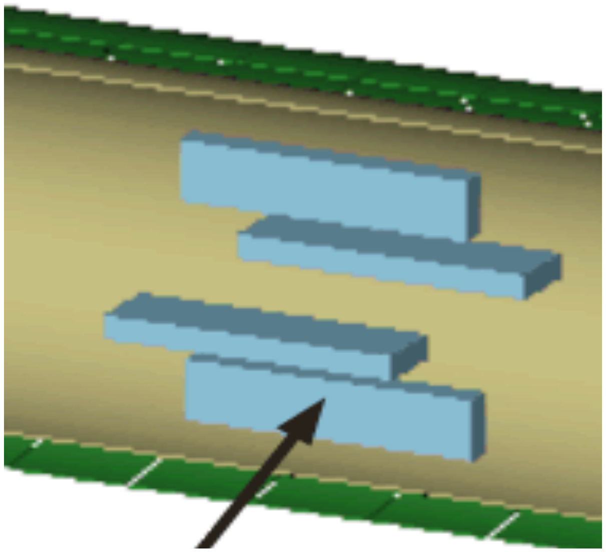


- ≈ 13,000 straws in vacuum.
- 70-130 cm long; 5 mm diameter.
- 260 sub-planes; ≈ 60 straws each.
- Conducting straws
  - Rates demonstrated in KTeV.
- Possible charge division?
- Straw ends are outside of the fiducial volume: support and readout easier.
- Issues:
  - Robust pattern recognition not yet demonstrated.
    - High priority to do so.

I-Tracker (I=Italian)

- Proposed by group from INFN Lecce.
- KLOE style cluster counting drift chamber.
  - Axial and stereo layers.
  - Central region empty (as with L and T).
- Advantage:
  - Robust pattern rec.; many measurements per track.
- Issues:
  - Material budget in upstream endplate.
  - Rates.

Crystal Calorimeter

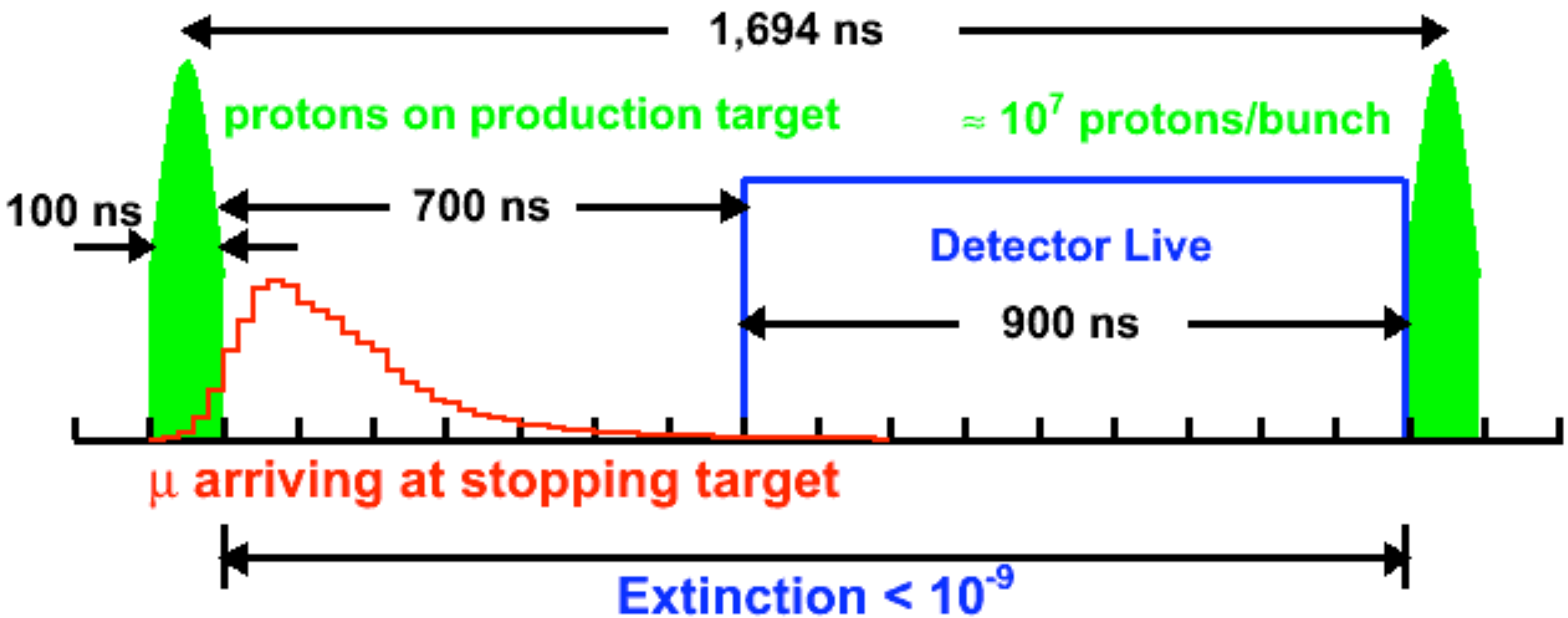


- 1024 $PbWO_4$ crystals.
  - 3.5×3.5×12 cm
- $\sigma(E)/E \approx 5$ MeV
- Main job is to trigger on interesting tracks.
- Spatial match of extrapolated track will help reject badly mis-reconstructed tracks.
- Most tracks from DIO curl inside.
- Pisa and LNF groups evaluating LXe which might provide good enough $\sigma(E/p)$ to be interesting.

Other Systems

- Active Cosmic Ray Veto
  - 3 Layers of 1 cm thick scintillator;
    - MINOS Style WLS fiber readout.
  - Requirement: 99.99% efficiency to veto cosmic rays.
- Muon Capture Monitor
  - One way to get at the denominator in Rμe.
  - Measure X-ray lines from muon capture on Al.
  - Ge detector located downstream of main beam dump.
  - Views target foils via tiny bore holes.
  - One way to get denominator of Rμe.

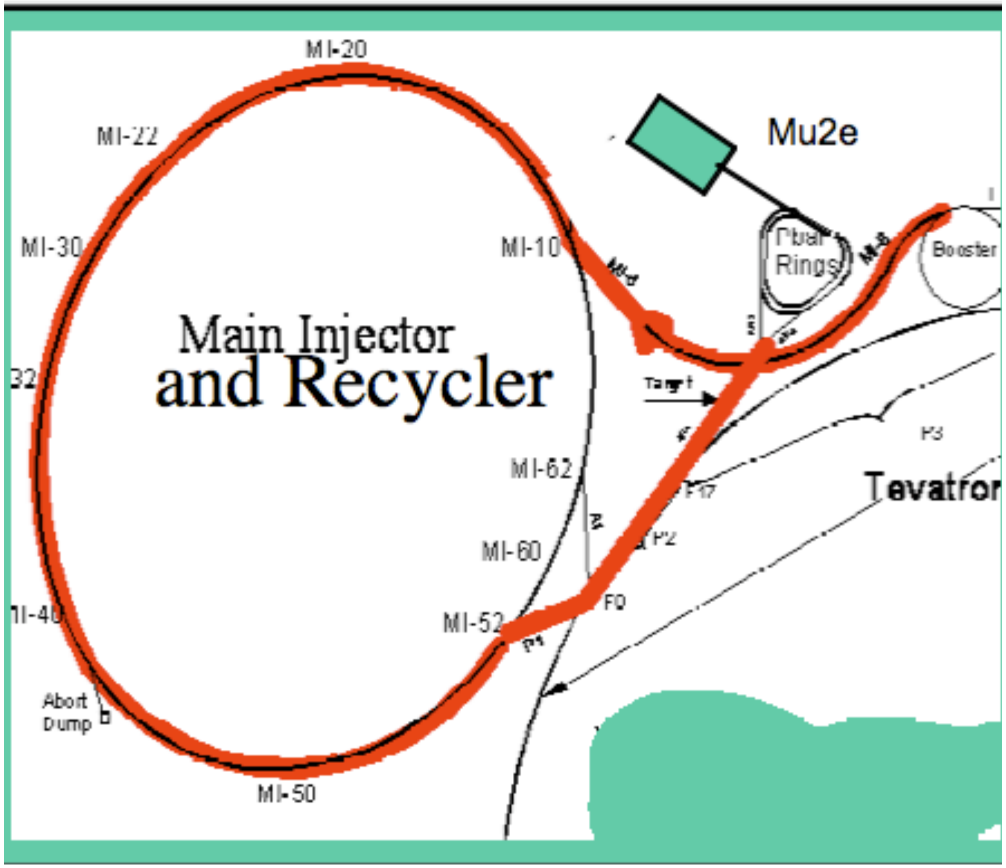
One Cycle of the Muon Beamline



- μ^- accompanied by e^-, e^+, π^-, …, which make backgrounds
- "Extinction" required to reduce backgrounds.
  - 1 out of time proton per 10^9 in time protons.
- Lifetime of muonic Al: 864 ns.

Proton Delivery and Economics

- Reuse existing Fermilab facilities with modest modifications.
- p-bar complex: 2 rings.
  - Use one ring as a “stash”.
  - Slow spill from the other.
  - 90% duty cycle slow spill.
  - Other schemes under study.
- Sharing p’s with NOVA:
  - NOVA 12/20 booster cycles.
  - Mu2e will use 6/20 cycles.

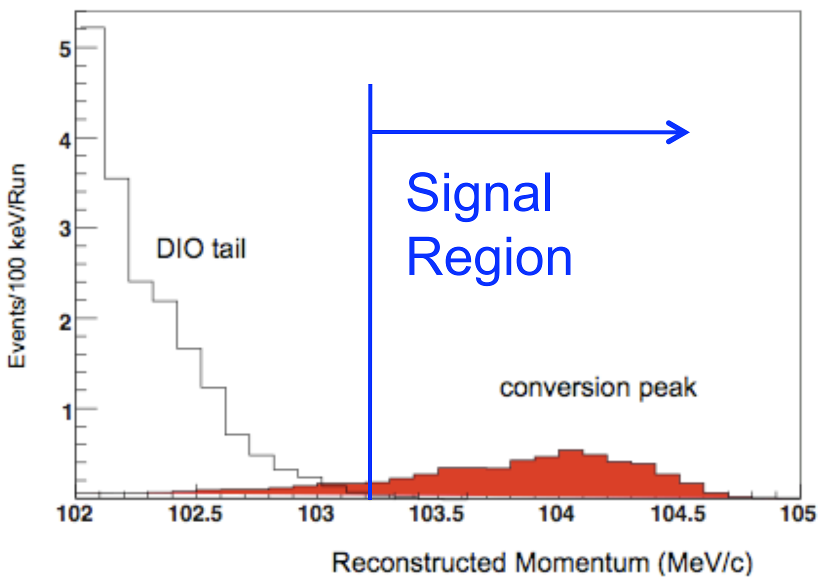


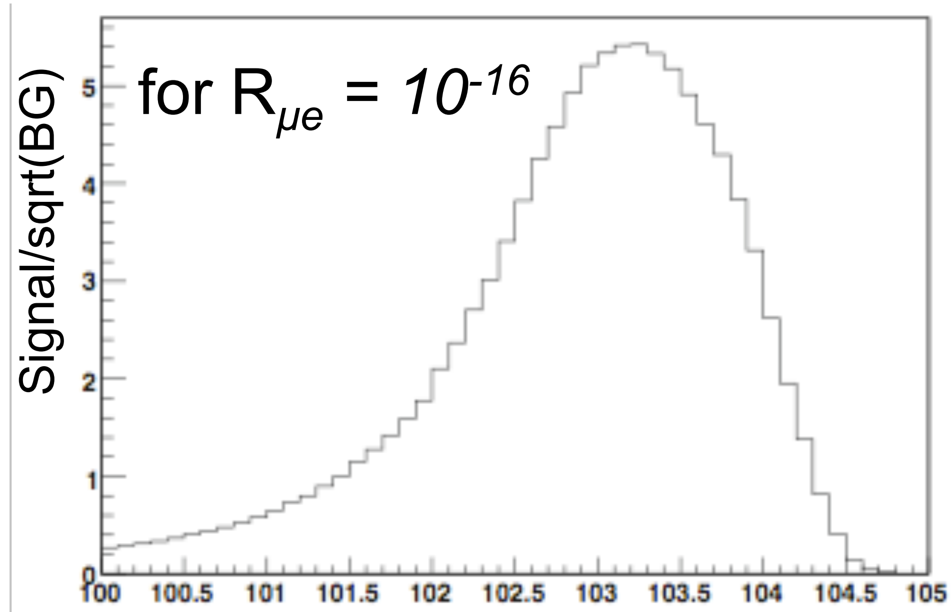
Making a stable, slow spill with a very intense proton beam is a big challenge.

Outline

- What is μ to e conversion? Why look for it?
- Cartoon of the experimental method.
- Theory overview.
- Details of the experiment.
- Backgrounds!
- Cost and Schedule.
- The Project X era.
- Conclusions.

Defining the Signal Region





Low Edge of Signal Region

- There is an irreducible background component.
- In addition, mis-measured DIO events can be reconstructed in the signal region. Critical to understand high side tails in the momentum resolution function.

Major Backgrounds

- From stopped μ^-
  - Decay in orbit (DIO) close to end point.
    - Irreducible component.
    - Mismeasured DIOs can smear into the signal region.
- Beam related (aka “prompt”):
  - Radiative π^- capture.
  - μ^- decay in flight + scatter in target.
  - e^- scattering out of beam.
- Cosmic rays

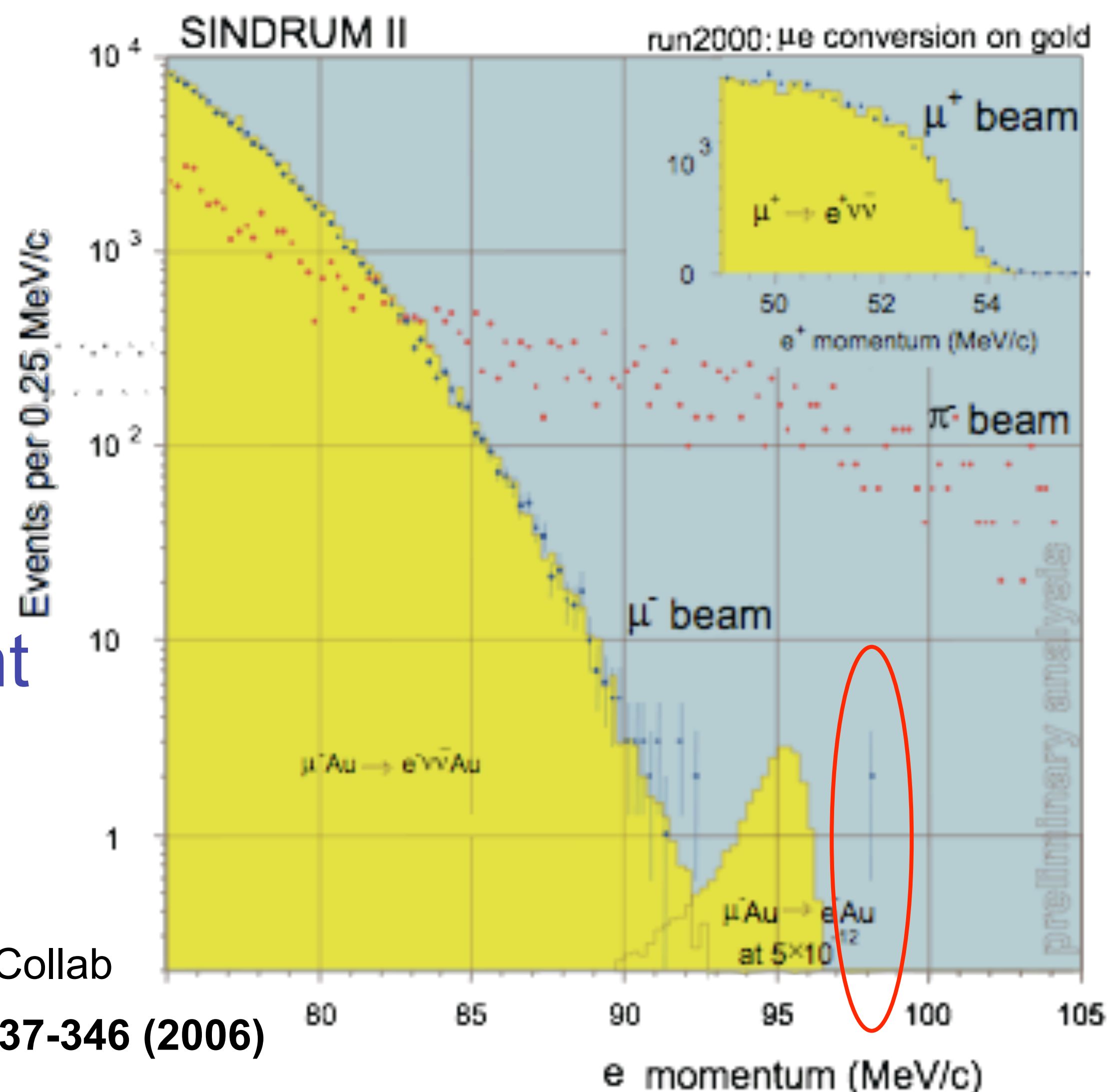
Radiative π^- Capture

$$\pi^- N(A,Z) \rightarrow \gamma X$$

- End-point of Eγ spectrum is m(π).
- Asymmetric conversions (internal or in material) can produce electrons at all energies up to m(π).
  - Includes the signal region.
- Believed to be the limiting background in SINDRUM II
- Mitigate by using pulsed beam with excellent extinction.

Previous Best Experiment

- SINDRUM II
- $R_{\mu e} < 6.1 \times 10^{-13}$ @90% CL
- 2 events in signal region
- Au target: different E_e endpoint than Al.



HEP 2001 W. Bertl – SINDRUM II Collab

W. Bertl et al, Eur. Phys. J. C **47, 337-346 (2006)**

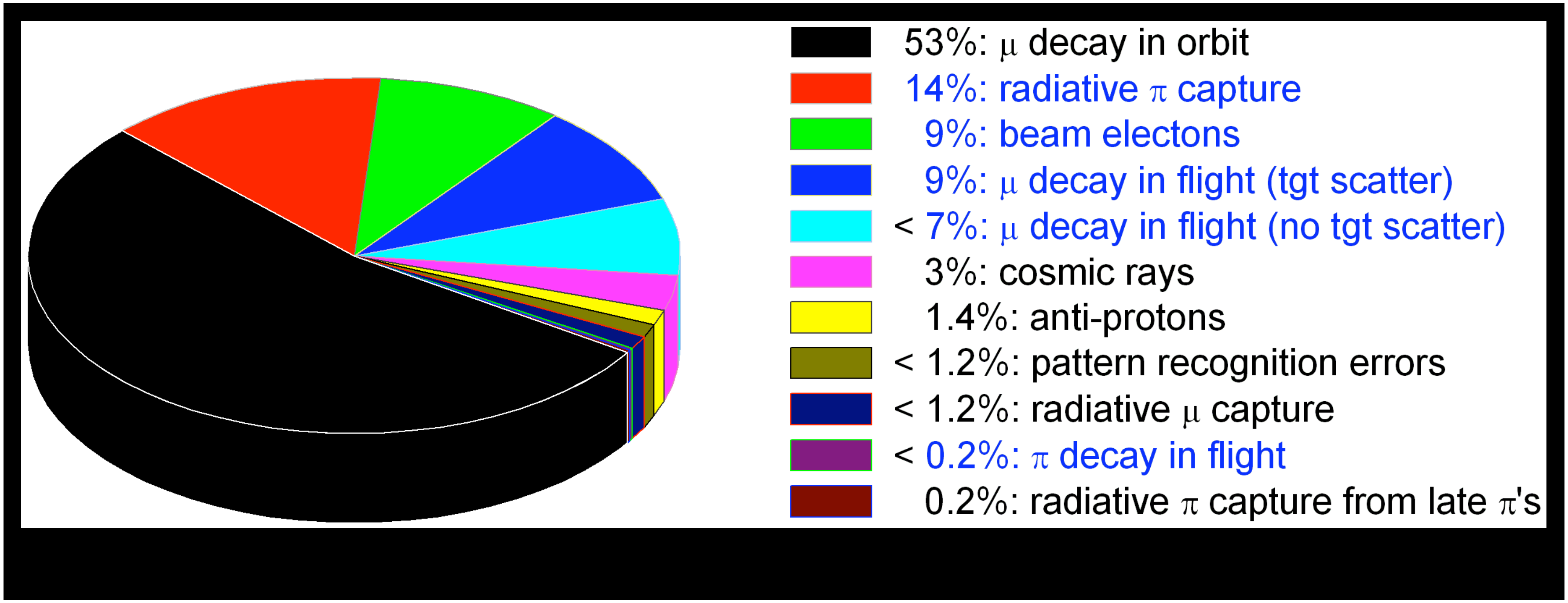
Backgrounds for 2×10^7 s Running

Source	Events	Comment
μ decay in orbit	0.225	
Radiative π^- capture*	0.063	From protons during detection time
Beam electrons*	0.036	
μ decay in flight*	0.036	With scatter in target
Cosmic ray induced	0.016	Assumes 10^{-4} veto inefficiency
Other	0.039	6 other processes
Total	0.42	

*: scales with extinction; values in table assume extinction of 10^{-9}.

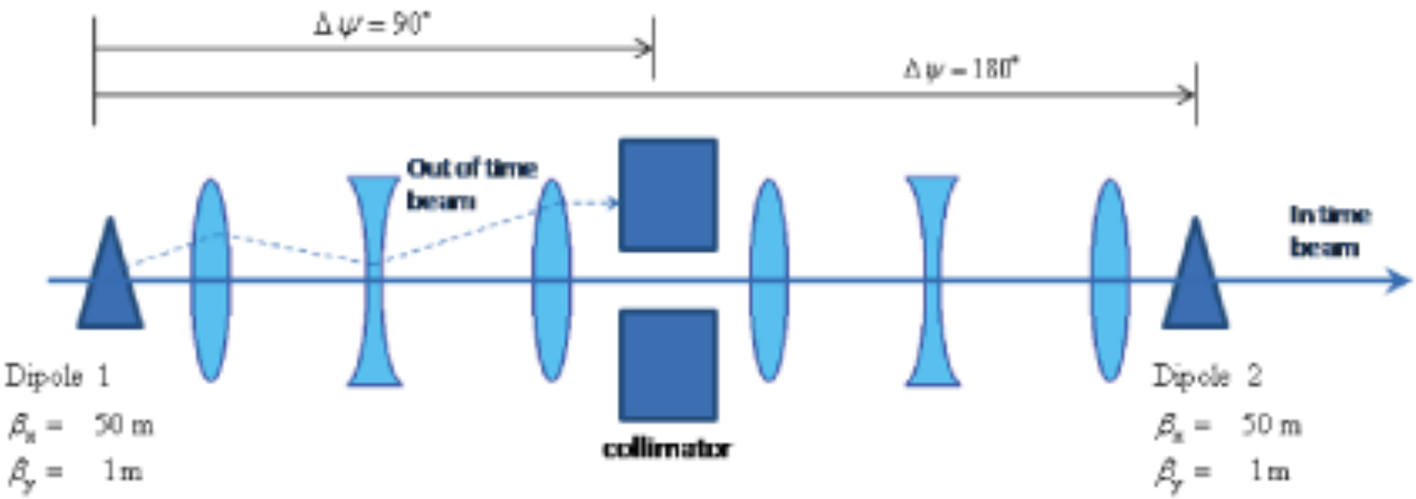
- Reduce DIO BG with excellent energy resolution, obtained by careful design of the tracker.
- Reduce next tier BGs with extinction.
- Reduce cosmic ray BG with shielding and veto.

All Estimated Backgrounds

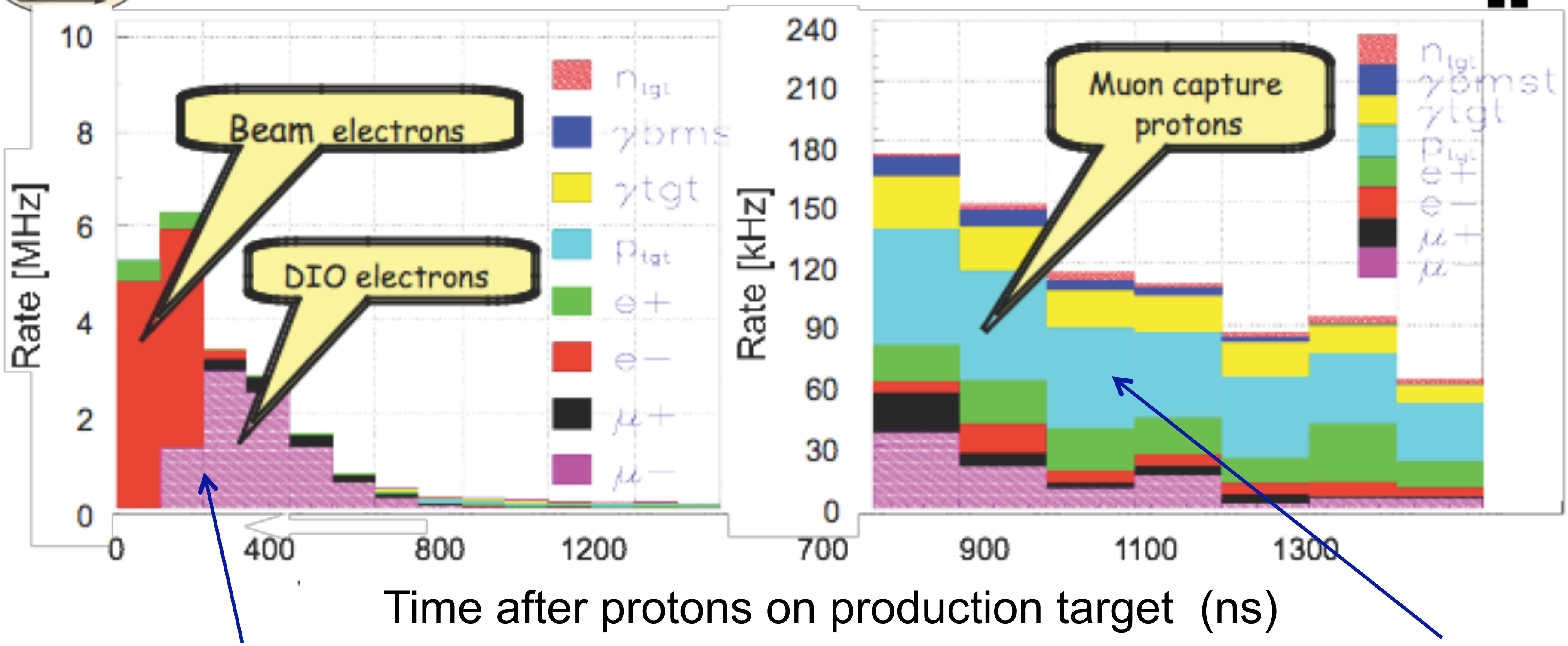


Required Extinction 10^{-9}

- Internal: 10^{-7} already demonstrated at AGS.
  - Without using all of the tricks.
  - Normal FNAL: 10^{-2} to 10^{-3}; but better has not yet been needed.
- External: in transfer-line between ring and production target.
  - Fast cycling dipole kickers and collimators.
- Monitoring techniques under study.



High Rates in the Tracker



Initial flash.

Each muon capture on Al: 2γ, 2n, 0.1 p

- Option: shield p from μ capture; but shield degrades resolution.
- Must prove that tracker design will perform robustly at these rates.
- Rates in live window imply an occupancy of O(1%).

Attacking Backgrounds

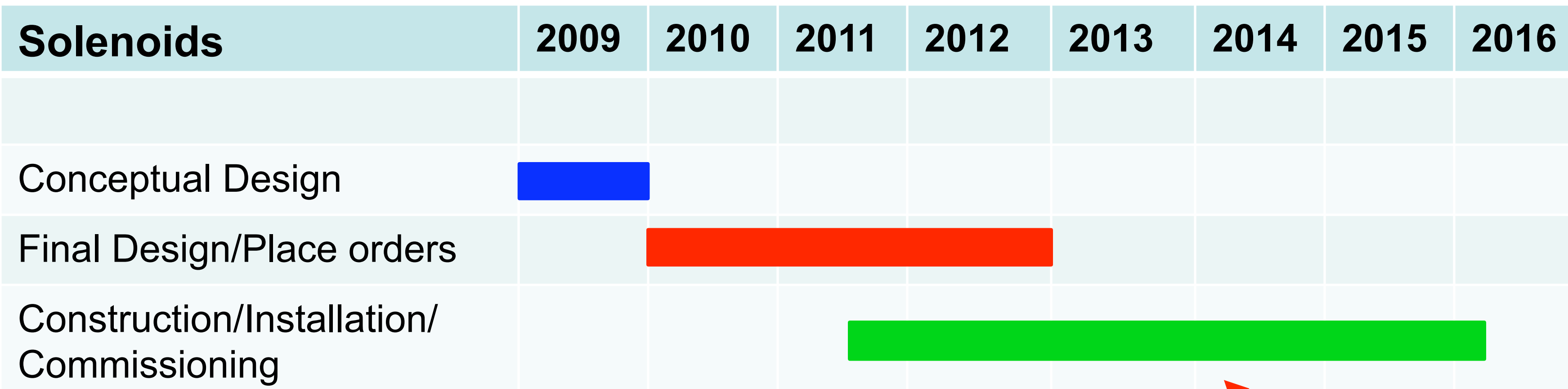
- Small standalone experiments
  - Learn how to measure the extinction.
  - Measure proton spectrum from μ^- capture on Al.
    - UIUC group last summer at PSI.
  - Opportunities for university groups.
- Special runs to measure backgrounds.
  - Switch polarity: μ^+ beam.
  - Lower intensity and earlier live window.
  - Lower field, look for $\pi \rightarrow e\nu$.
  - Dedicated cosmic runs.
  - None is a silver bullet by itself.

Outline

- What is μ to e conversion? Why look for it?
- Cartoon of the experimental method.
- Theory overview.
- Details of the experiment.
- Backgrounds!
- Cost and Schedule.
- The Project X era.
- Conclusions.

Estimated Cost and Schedule

- Estimated Total Project Cost O(M$200.).
  - Fully loaded, escalated. Overall contingency ≈50%.
- Critical path: solenoids.
  - – Technically limited schedule:



- R&D going on now or soon.
  - PSI: products of μ capture on Al.
  - FNAL: Extinction tests; straw tests.

Now

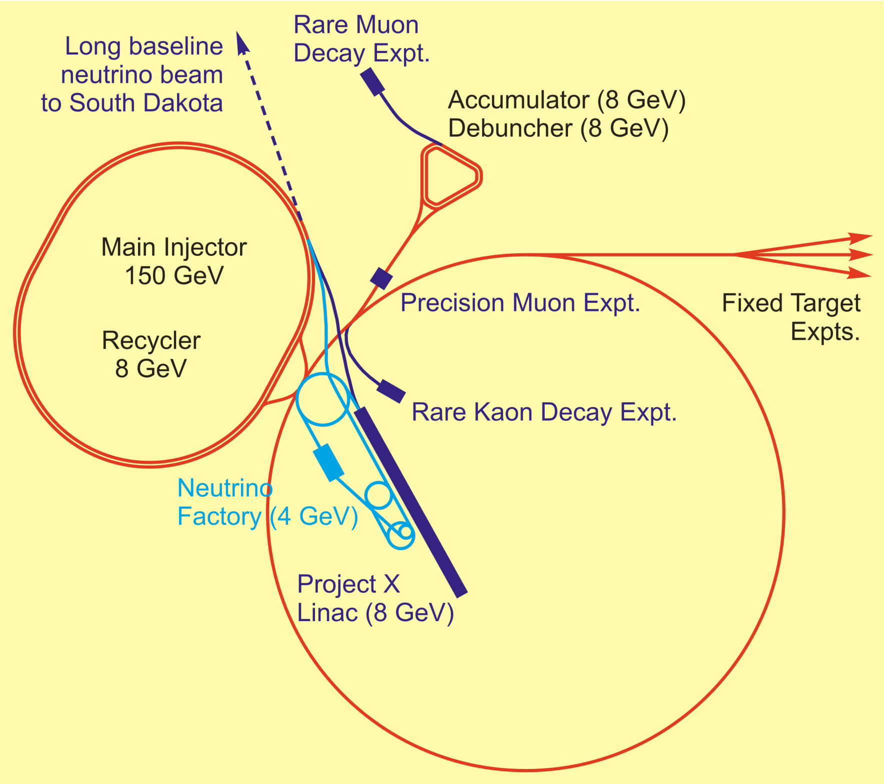
Opportunities for university groups.

Outline

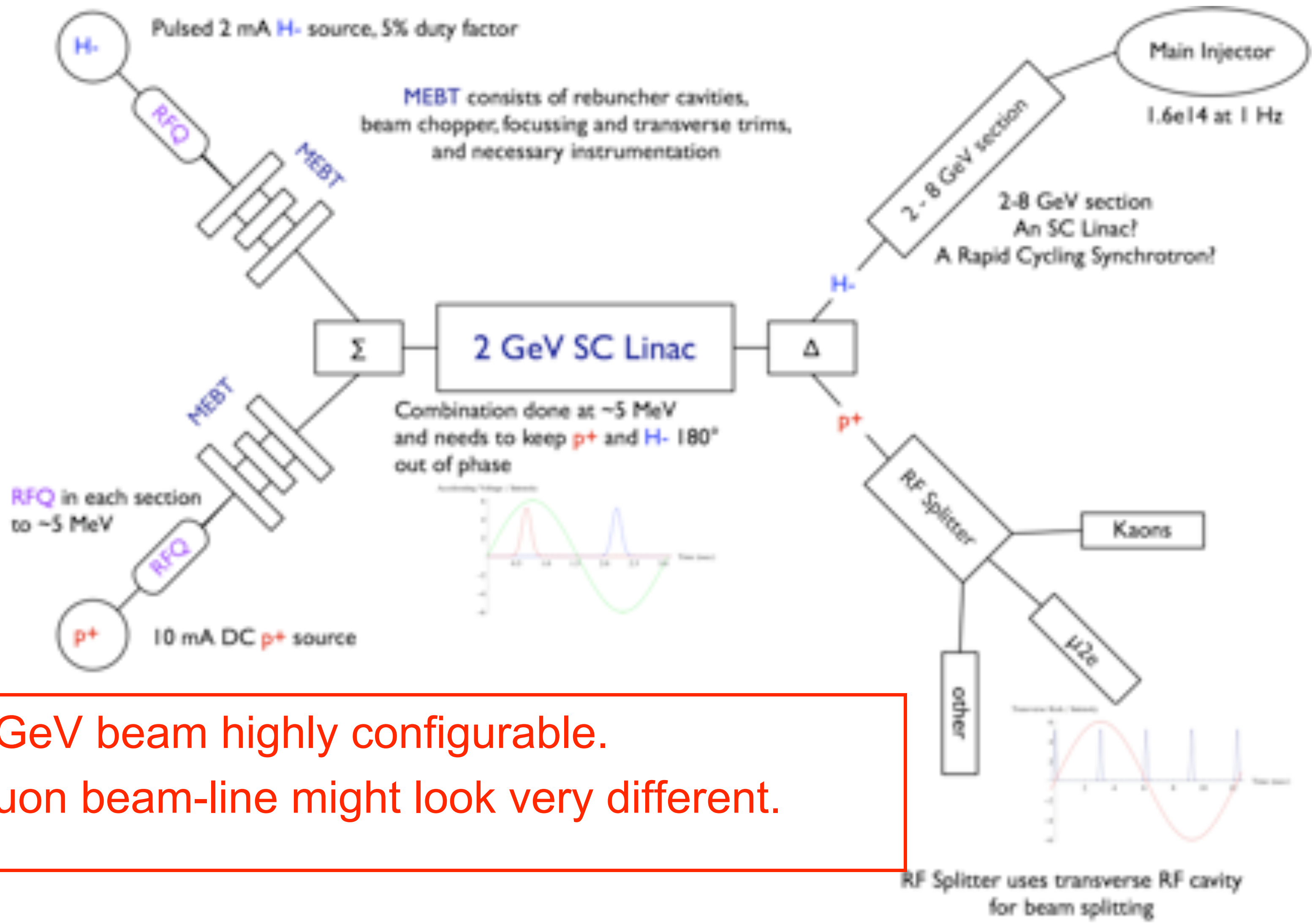
- What is μ to e conversion? Why look for it?
- Cartoon of the experimental method.
- Theory overview.
- Details of the experiment.
- Backgrounds!
- Cost and Schedule.
- The Project X era.
- Conclusions.

Mu2e In the Project X Era

- Project X: high intensity proton source to replace existing Booster.
  - Booster: 20 kW beam power at 8 GeV.
  - Project X: 200 kW at 8 GeV (with upgrade path to 2000 kW).
  - With corresponding upgrades at 120 GeV.
- If we have a signal:
  - Study Z dependence by changing stopping target.
  - Helps disentangle the underlying physics.
- If we have no signal:
  - Up to to 100 × Mu2e physics reach, $R_{\mu e} < 10^{-18}$.
  - First factor of ≈10 can use the same detector.



Project X ICD-2



- 2 GeV beam highly configurable.
- Muon beam-line might look very different.

Project-X Related Links

- 4^{th} Workshop on physics with a high intensity proton source, Nov 9-10, 2009.

http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-physics-4th.html

- Muon Collider Physics workshop, Nov 10-12, 2009.

http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-muoncollider.html

- Fermilab Steering Group Report, June 2008.

http://www.fnal.gov/directorate/Longrange/Steering_Public/

Summary and Conclusions

$$\boxed{\mu^- N \rightarrow e^- N}$$

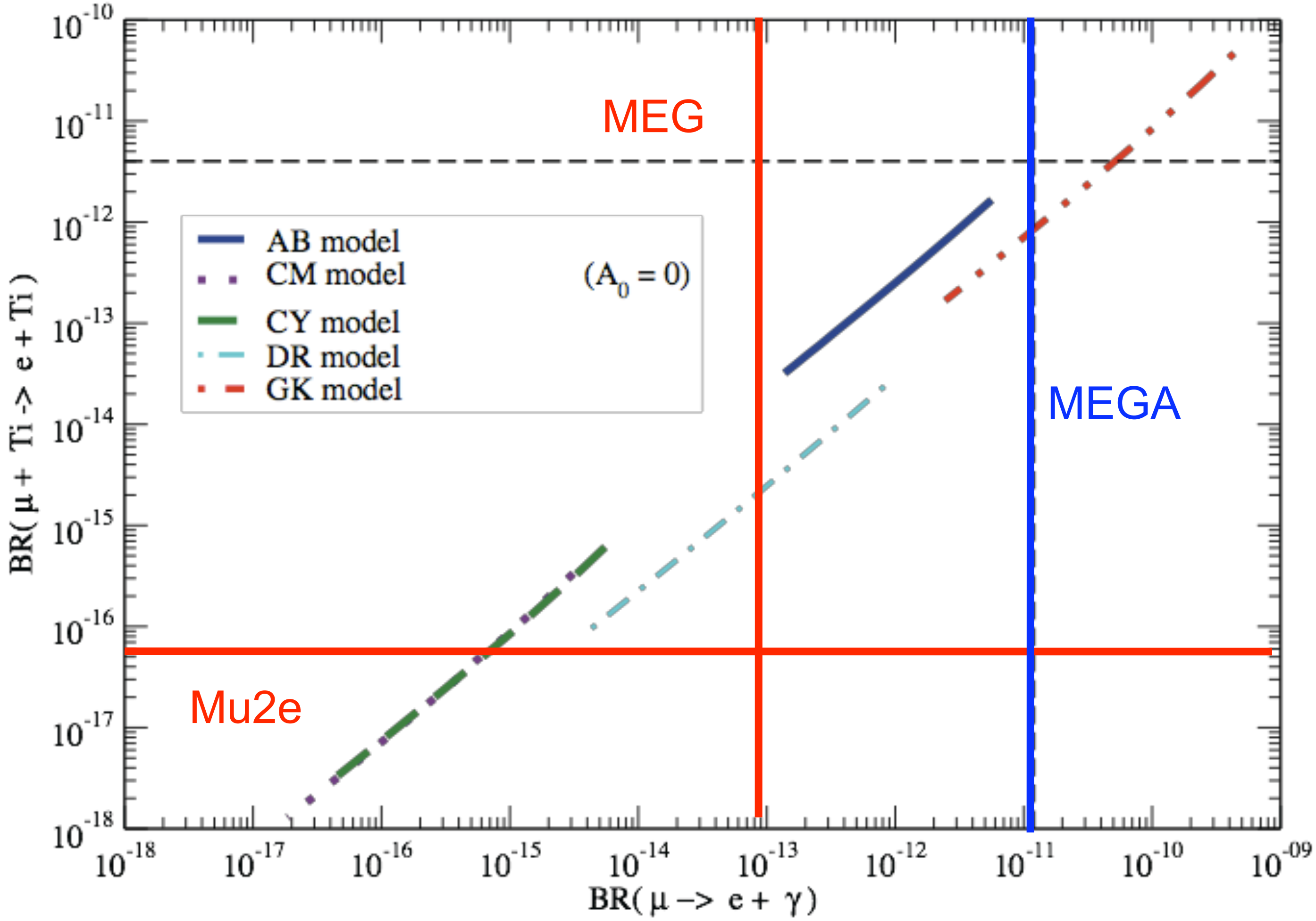
- Sensitivity for 2 years of running:
  - Discover new physics or Rμe < 6 ≈ 10^{-17} @ 90% CL.
  - Mass scales to O(10,000 TeV) are within reach.
  - 10,000 × better than previous best limit.
- Many SUSY@LHC scenarios predict Rμe ≈ 10^{-15},
  - Expect 40 events with < 0.5 events BG.
- Critical path is the solenoid system:
  - Technically limited schedule: startup possible in 2016.
- Project X era:
  - If a signal, we can study N(A,Z) dependence.
  - If no signal, improve sensitivity up to 100 ×, Rμe < O(10^{-18}) .
- Opportunities for new university groups.

For Further Information

- Mu2e home page: http://mu2e.fnal.gov
- Mu2e Document Database:
  - http://mu2e-docdb.fnal.gov/cgi-bin/DocumentDatabase
  - Mu2e Proposal: Mu2e-doc-388
  - Mu2e Conference presentations

Backup Slides

Combining Conversion and μ➔eγ



C. Albright and M. Chen, arXiv:0802.4228, PRD D77:113010, 2008.

DOE Order 413.3A

- CD-0: Approve Mission Need
  - A determination is made that there is a scientific case to pursue the project. Some of the possible alternative means of delivering the science are presented as well as a coarse estimate of the cost.
- CD-1: Approve Alternative Selection and Cost Range
  - One of the alternatives proposed in the CD-0 is selected and a credible cost range is established.
- Critical Decision 2: Approve Performance Baseline
  - The technical scope of work, the cost estimate, and the construction schedule is sufficiently well known that the project can be completed on time and within budget.
- Critical Decision 3: Approve Start of Construction
  - Engineering and design are sufficiently complete that construction, procurement, and/or fabrication can begin.
- Critical Decision 4: Approve Start of Operations
  - The project is ready to be turned over to the organization that will operate and maintain it. The criteria for this stage are defined in the Performance Baseline.

http://www.er.doe.gov/hep/project_status/index.shtml

Intellectual Precursors

- 1992:
  - Collection scheme using solenoids proposed by MELC collaboration at Moscow Meson Factory.
- 1997-2005:
  - MECO proposed to run a BNL.
  - Cancelled when entire RSVP program was cancelled.
  - Mu2e design starts from MECO design.

PAUL SCHERRER INSTITUT

Background : b) pion induced

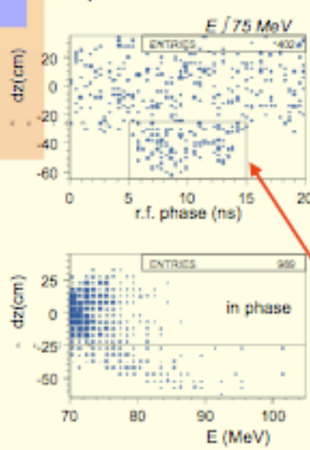
Radiative Pion Capture (RPC) : $\pi^- Au \rightarrow \gamma + Pt^*$ followed by $\gamma \rightarrow e^+ e^-$

Kinematic endpoint of photon spectrum around 130 MeV ! *Branching ratio of order 2%.*

No way to distinguish an asymmetric $e^+ e^-$-pair (with little e^+ energy and e^- energy at 95 MeV) from μe !

⇨ Needs strong pion suppression : only ~ 1 pion every 5 minutes is allowed to reach gold target!

positron distributions

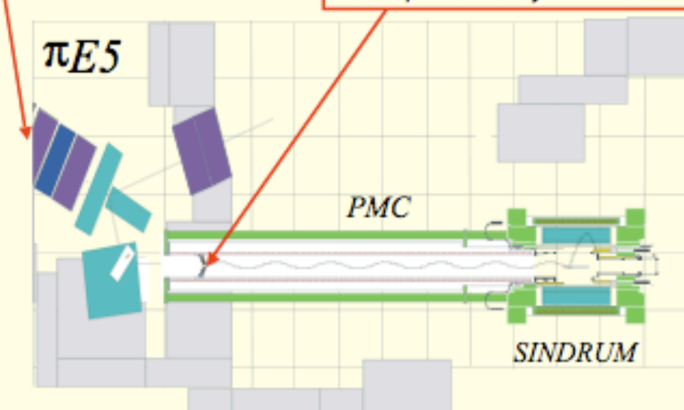


⇨ use solid angle and cyclotron phase correlation to cut.

***BUT:** Degrader is now pion stop target → e^+e^- pairs from RPC are collected by B_{PMC} and transported towards the gold target where they may scatter into spectrometer acceptance (typ. forward scattering)*

⇨ tune beamline to suppress high momentum tail

*⇨ use **degrader** 8m in front of gold target to separate μ's and π's by their different stopping power. Penetrating slow pions decay in PMC.*



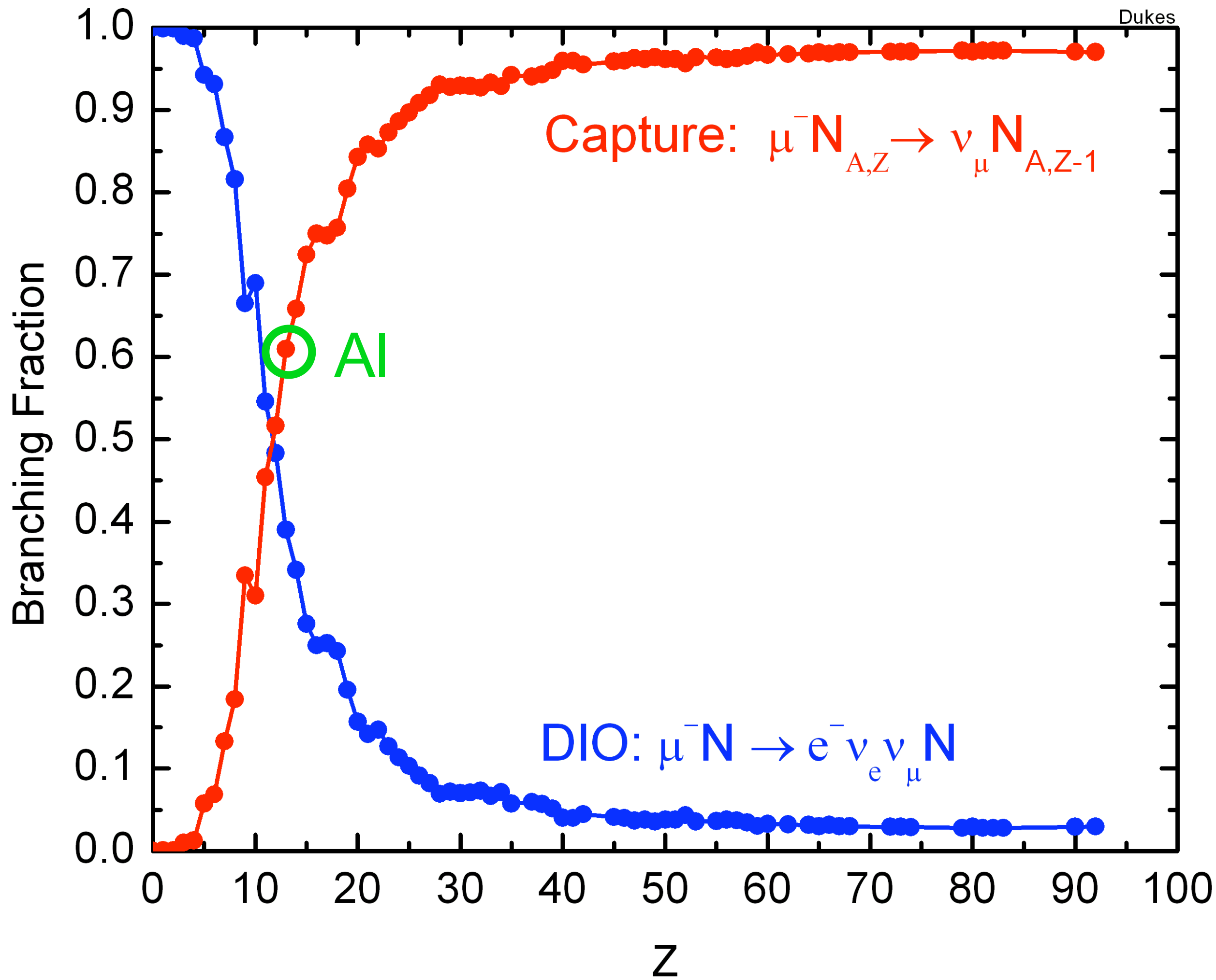
July 14, 2001

HEP 2001 (W.Bertl - SINDRUM II collaboration)

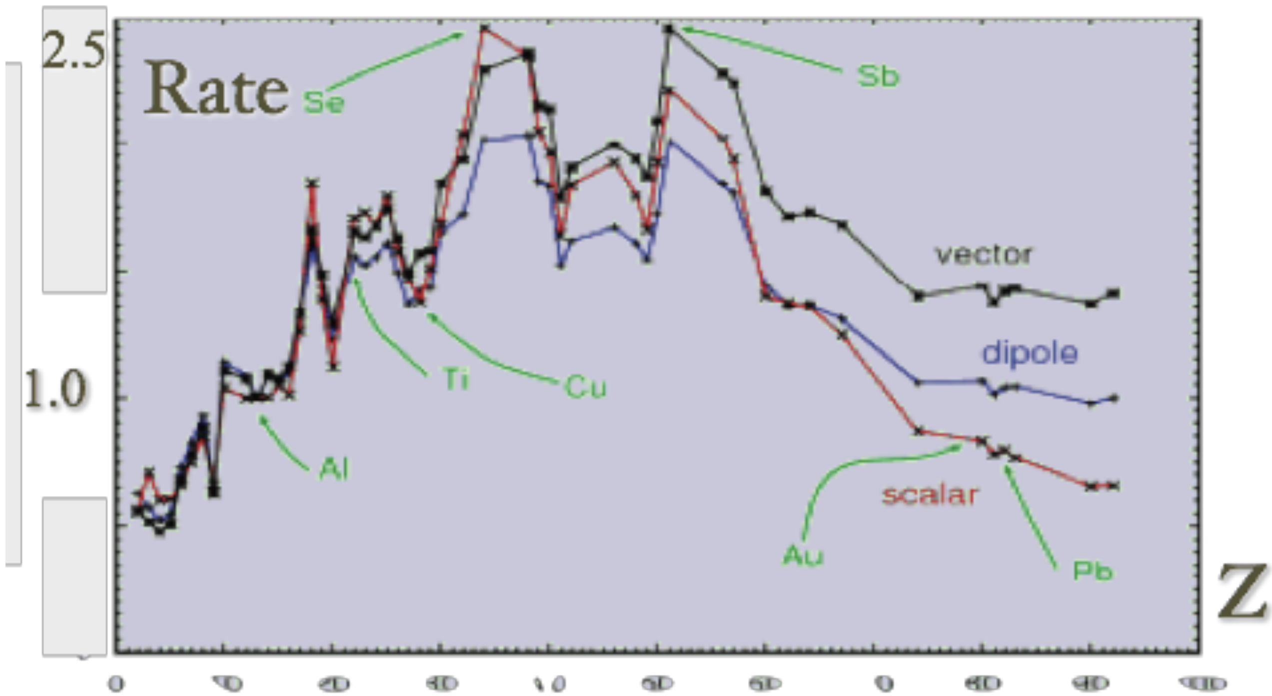
Why is Mu2e Better than SINDRUM II?

- FNAL can deliver ≈1000 × proton intensity.
- Higher μ collection efficiency.
- SINDRUM II was BG limited.
  - Radiative π capture.
  - Bunched beam and excellent extinction reduce this.
- So Mu2e can effectively use the higher proton rate.

Capture and DIO vs Z



Conversion Rate, Normalized to Al



Kitano, et al., PRD 66, 096002 (2002)

Backgrounds for 2×10^7 s Running

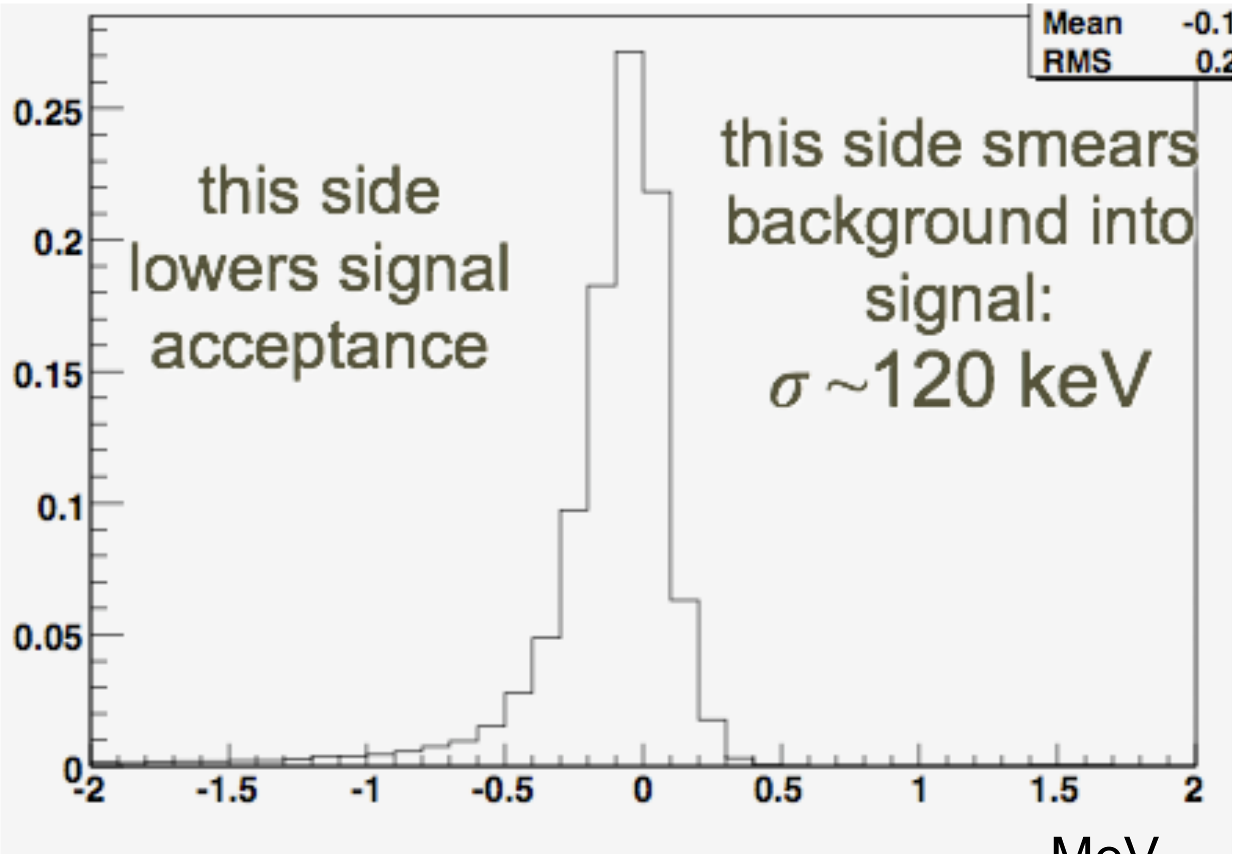
Source	Events	Comment
μ decay in orbit	0.225	
Pattern Recognition Errors	<0.002	
Radiative μ capture	<0.002	
Beam electrons*	0.036	
μ decay in flight*	<0.027	without scatter in target
μ decay in flight*	0.036	with scatter in target
π- decay in flight*	<0.001	
Radiative π^- capture*	0.063	from protons during live gate
Radiateive π^- capture	0.001	from late arriving π^-
Anti-proton induced	0.006	
Cosmic ray induced	0.016	
Total	0.415	

*: scales with extinction; values in table assume extinction of 10^{-9}.

Why Look for CLFV?

- At our expected sensitivity:
  - There are no standard model backgrounds.
  - Therefore any observation is evidence for physics beyond the Standard Model (SM).
- Many beyond the SM scenarios predict observable rates for Mu2e.
- Mu2e is sensitive to new particles with masses up to O(10,000 TeV).
- Presence/Absence of particular CLFV signals can help remove ambiguities from LHC new physics signals.

Momentum Resolution for L-Tracker



(Measured-Generated) Momentum

Generated = at entrance to the tracker

Critical to understand the tails on high side of the distribution.

Can catastrophic pattern recognition failure produce a false signal?